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PUBLICATIONS OF THE INSTITUTE OF MARINE SCIENCE

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Ecological Implications of the Behavior of the Sexually Dimorphic Goby *Microgobius gulosus* (Girard)

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Abstract

A common goby (*Microgobius gulosus*) of the Gulf Coast was found to be sexually dimorphic in size, coloration, and mouth proportions. Evidence indicates a carnivorous diet. Males are able to ingest significantly larger food items, both artificial and natural, than are females. Aggressive behavior, threat behavior, and territoriality are described. Niche expansion and differential niche utilization, by virtue of sexual dimorphism, has most likely occurred.

Introduction

Sexual dimorphism in vertebrates is a widespread phenomenon. Sexual differences involve not only size and coloration but also the proportions of morphological characters such as limbs, fins, and mouth parts (Amadon, 1959). These differences, however, have been frequently ignored by ecologists. Theoretical studies of ecological variation in animal populations and actual field studies have been made by da Cunha and Dobzhansky (1954), Li (1955), Dobzhansky (1961, 1963), Pitelka (1950), and Selander (1964). These studies, coupled with modern theory concerning polymorphism (Ford, 1961) and natural selection (Mayr, 1963) indicate that sexual dimorphism is ecologically important and should be investigated further.

This paper presents the results of a study of the ecology and behavior of a species of fish, *Microgobius gulosus,* which shows marked sexual dimorphism both in size and in body proportions. The full significance of sexual dimorphism and niche relationships may be obtained only after studying many species showing this characteristic.

Methods and Materials

Several collections of *Microgobius* were obtained from Nine Mile Pond near Rockport, Texas. Measurements of salinity, depth, and temperature of the pond were made. Fourteen individuals were used for live experimentation and observations. Three males and five females were placed in a glass, salt water aquarium, 45 × 125 cm and 45 cm deep. Two groups consisting of two males and four females were placed in two tanks, 25 × 50 cm and 32 cm deep. Water temperature was 24 ± 2 C, and the water was recycled daily. Observations were made at various intervals during the day and night and at the daily feeding.

Food for experimentation consisted of cut strips of raw shrimp (*Penaeus*) measuring 10 or more mm or 7 or less mm in length. The approximate width was 3 to 5 mm. Olfaction experiments consisted of soaking filter paper in oyster extract or in a mixture of

four to ten common amino acids and placing the paper on the bottom of the tank. Fish were starved for several days to insure response. Various other food organisms were introduced at different times for observation of feeding behavior. These food organisms were amphipods, larval shrimp, and small larval or post-larval fish of various species, including larval forms of *Microgobius gulosus*. These organisms were collected from Nine Mile Pond.

Preserved specimens were measured and then dissected for stomach analysis and examination of internal anatomy. Measurements were made of standard length, head length, upper jaw length, pelvic fin length, and head width (Hubbs and Lagler, 1949). Observations were made of six *Gobiosoma bosci* for comparison.

Results

Sexual Dimorphism

At one time the two sexes of the strongly dimorphic *Microgobius* were described as different species. Ginsburg (1934) was the first author to describe them as the same species. He noted the marked difference in color pattern and mouth size. For a small sample size he found the males to vary between 53 and 62 mm and the females from 47–62 mm. Figs. 1 and 2 illustrate the degree of dimorphism in linear dimensions and the ratio of upper jaw length to standard length and to head length. There is little to no overlap in either ratio distribution, indicating a disproportionately larger mouth in the male than in the female. Fig. 3 illustrates: the differences in size, shape, and coloration of the dorsal fin, pigmentation of the soft dorsal and anal fins, body and caudal fin pigmentation, and size and shape of mouth.

Internal Anatomy

An examination of the internal anatomy of 52 fish in July, 1964, revealed that all were sexually mature. The following features of ecological interest were noted:

1. *Microgobius* has a large well developed air bladder in contrast to most gobiids (Lagler et al., 1963). Specimens of *Gobiosoma bosci*, a known bottom dweller, had a much smaller bladder.
2. The intestine is relatively short and S-shaped.
3. The gill rakers are only moderately developed.
4. With the exception of the gonads, no internal sexual dimorphism was found.

General Habitat

Extensive collections in the Aransas and Corpus Christi Bay area failed to reveal any adult populations. Occasionally, however, specimens have been reported and larval forms have been observed in inland bays.

Nine Mile Pond has been separated from Aransas Bay since 1961 and probably much earlier (Hubbs, 1961). The deepest area is approximately 7 or 8 feet. Salinity during the month of June, 1964, averaged 35 ppt, although previously it had fallen as low as 10 ppt (Hubbs, 1961). Surface temperatures during June and July, 1964, varied between 29 and 35 C while bottom temperatures ranged from 29 to 32 C. The bottom was composed

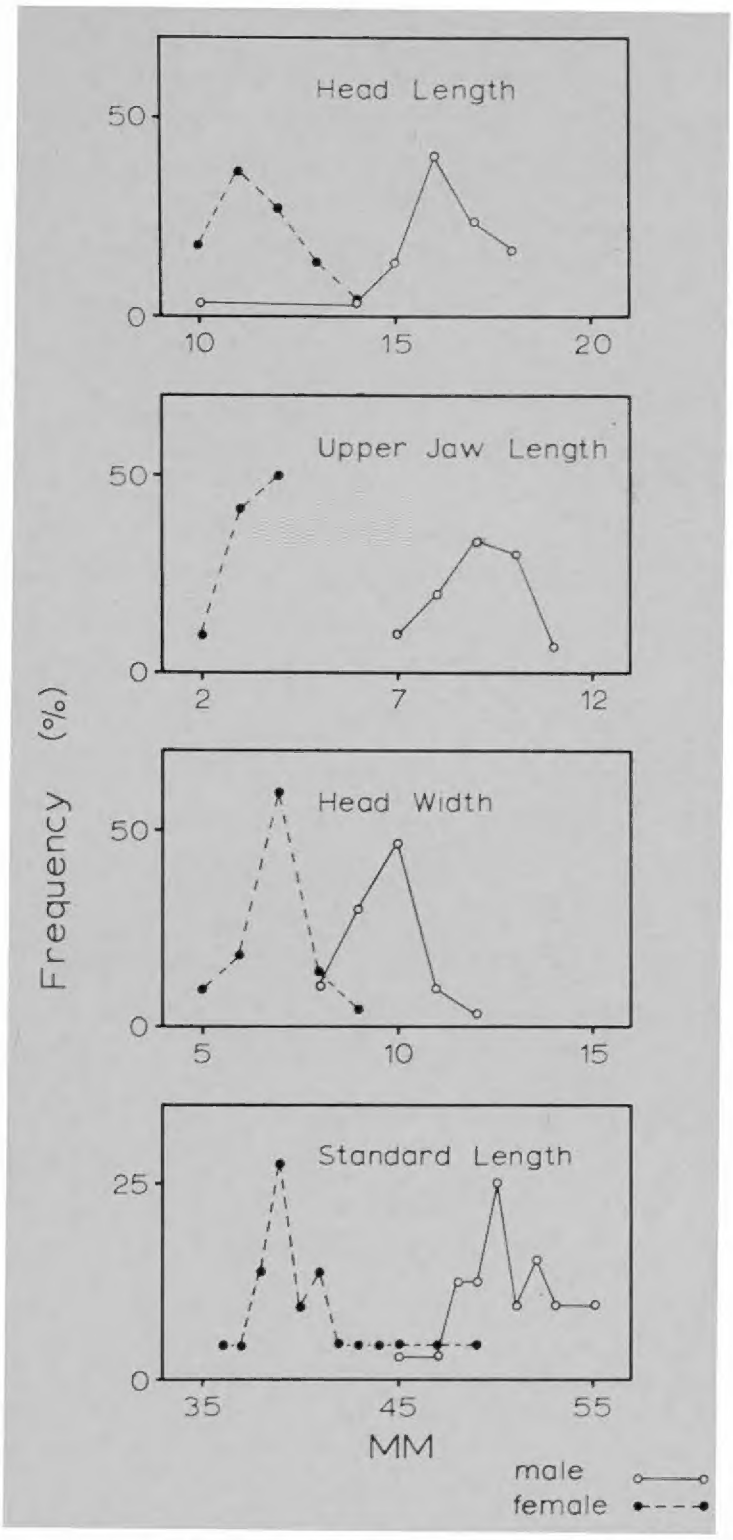

FIG. 1. Per cent frequency of head length, upper jaw length, head width, and standard length of *M. gulosus* males and females. All length and width measurements are in mm.

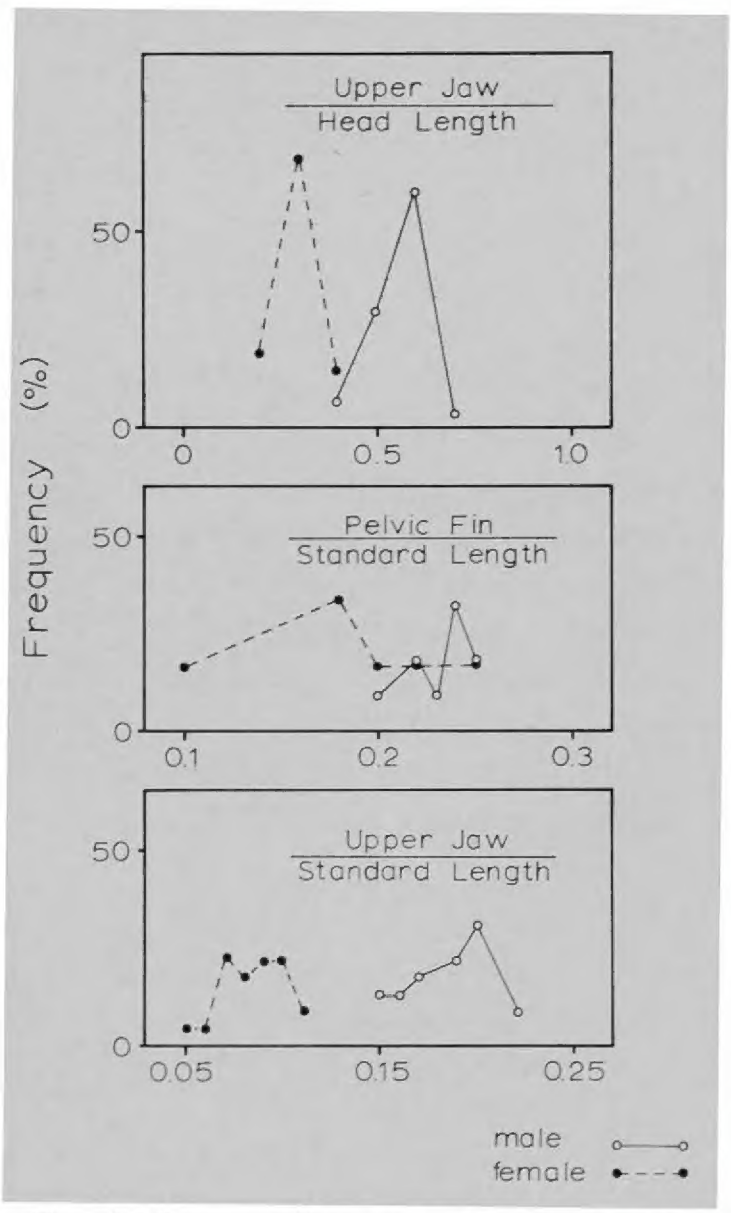

FIG. 2. Per cent frequency of upper jaw to head length, pelvic fin to standard length, and upper jaw to standard length ratios for *M. gulosus* males and females.

of mud with little vegetation. This agrees with Ginsburg's (1934) finding of *Microgobius* on muddy bottoms in the inner ponds and bayous of the Gulf Coast.

Using plankton samples, *Microgobius* from 10 mm larvae to adults were obtained, possibly indicative of a long breeding season.

FOOD AND FEEDING BEHAVIOR

Stomach analyses results were not completely satisfactory. Due to the low percentage of individuals with identifiable food and to the apparently rapid digestion occurring in the stomach few conclusions can be drawn. Larval shrimp and amphipods appeared to be common items of the diet.

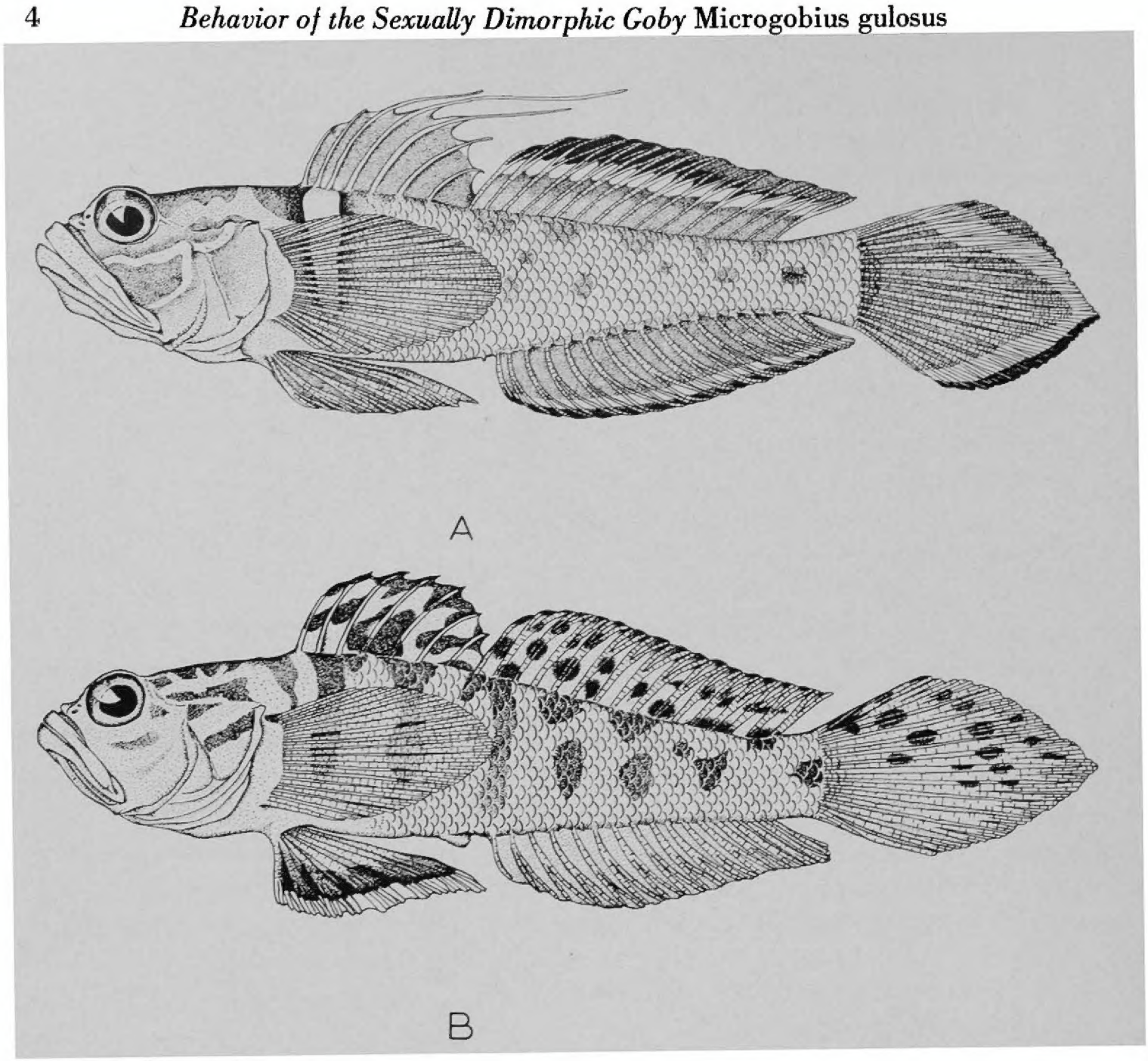

FIG. 3. *Microgobius gulosus.*
A. Adult Male—note color pattern and mouth size.
B. Adult Female—note much smaller mouth size in relation to body length.

In the aquarium *Microgobius* fed on a wide variety of food items. Amphipods, larval shrimp, and larval fish from a few mm to about 20 mm were eaten indiscriminately. Those organisms longer than approximately 20 mm were approached and often bitten, but in only one case were they actually eaten. In this instance a large male engulfed an atherinid (*Menedia beryllina*) of approximately 25 mm. *Microgobius* fed on its own larvae which fell in the appropriate size class.

The manner in which food is taken is ecologically important. These fish are vigorous swimmers and are able to maintain themselves off the bottom for long periods of time. This is not surprising in view of their large air bladder. In contrast, *Gobiosoma* was decidedly negatively bouyant. *Microgobius'* feeding movements resembled those of the fresh water sunfish *Lepomis*—a quick dart and rapid engulfing of the food object. They could easily take food off the bottom although movement of the food substance was necessary before a feeding reaction would commence. A fish starved for several days reacted strongly to any movement which indicated food; whereas food placed on the bottom was usually untouched.

Olfaction experiments with *Microgobius* using an amino acid mixture or oyster ex-

tracts brought no reaction when the filter paper was introduced. But *Gobiosoma* reacted with vigorous feeding behavior upon this introduction. The indication here is that feeding is largely a response to visual stimuli.

Aggressive Behavior, Threat Display, and Fighting

Chasing, nipping, threat displays, fighting, and territorial defense were observed in *Microgobius*. Nipping, often seen in conjunction with chasing, consisted of biting movements and usually did not involve contact. Fighting, an unusual behavior, was observed in one instance, and was of extremely short duration. Threatening involved various displays described below.

Nipping and chasing were the two most common forms of aggressive behavior and were manifested principally by the males. Females also showed this behavior, particularly just prior to and during feeding. A social order was not observed in *Microgobius*. Although one male and one female were dominant, no further social hierarchy could be observed. The largest male was the dominant fish in the large aquarium and it nipped all others with equal frequency. Aggressive actions of the other members were directed reciprocally (excluding the dominant male) with apparent equality. Aggressive behavior was sporadic and periods elapsed when no aggressive behavior appeared. Males tended to remain in one vicinity for hours and actively defended this area against intruding males. Intruding females were sometimes approached but were not threatened. The dominant male was the most active in establishing and maintaining a territory. Although no precise territorial boundaries could be discovered, the following were noted:

1. The dominant male showed no threat behavior toward males which were more than ½ the tank length away.
2. Territories tended to shift about to some degree and territorial behavior was infrequent.
3. Aggressive behavior increased markedly just prior to and during feeding.
4. The presence of the dominant female tended to increase territorial behavior in the dominant male.

The most complete and elaborate threat display occurred when the dominant male in the small tank was introduced into the larger tank. The display began with the fish approaching each other in the "head on" fashion. There was then maneuvering which placed one fish at right angles to the other fish. When this occurred the crossing fish tended to arc its body and caudal fin toward the other. This was usually sufficient to send the non-crossing fish in immediate retreat, the other nipping at his caudal area. In rare instances however, the latter action was not sufficient in which case both fish faced off again. In this position the mouth was opened to its maximum extent and the large pectoral fins outstretched. With the exception of one instance this behavior resulted in the fleeing of one individual. During this whole sequence the median fins were fully extended displaying their usual color pattern. Appeasement behavior involved retraction of the median fins and the inclination of the body 45° from the vertical or an upward fleeing movement. The subordinate fish in all encounters showed this behavior.

Differential Niche Utilization

The data for feeding experiments using different sized foods showed that of 46 trials the food of greater than 10 mm in length was eaten by males 41 times. Of the food 7 or

less mm in length, 23 of 59 trials resulted in the food being eaten by males. Using an expected value of approximately 50% in each series of trials, the chi square values showed $P<0.001$ for the first set and an insignificant value for the second set of trials ($P>0.05$). Thus, males ingested significantly larger food items than females. In many instances a female would attempt to eat a large particle of food, find it too big to swallow and eventually reject it.

It was found that the males were able to eat larger, live, natural food items than were the females. In many instances it was observed that a female would attempt to engulf prey only to reject it. Upon its rejection a male would engulf it with little visible effort. Due to the male's ability to take smaller food, it was not determined whether they preferred larger food items. Males tended to eat the nearest food item, large or small. This, coupled with their seemingly small appetite, thwarted preference experiments.

Discussion

In the present study the ratio of upper jaw length to both standard length and head length shows that the mouths of the two sexes differ disproportionately. The female is not just a smaller version of the male. This observation is similar to Selander's (1964) finding in melanerpine woodpeckers.

The differences in color pattern probably function in display. The effect of sign stimuli or releasors in fish has been well documented (Tinbergen, 1951, and 1953; Stringer and Hoar, 1955).

Two important aspects of the internal anatomy of *Microgobius* and feeding behavior need to be considered. The shape of the intestine and gill rakers provide evidence for a carnivorous mode of life. Observations on the importance of movement and the unimportance of olfaction in feeding and the types of food taken contribute further evidence to this conclusion.

Aggressive behavior in fish has been well documented (Tinbergen, 1953; Stringer and Hoar, 1955). Magnuson's (1962) work with Medaka (*Orysias latipes*) showed that aggressive behavior increased during feeding. Present results concur.

Ritualized threat behavior and the presence of territoriality are possible correlates of sexual dimorphism and undoubtedly play an important part in the life history of *Microgobius*. In holding and maintaining territories selection would probably favor a large male. Magnuson (1962) demonstrated the importance of large size in dominance in the Medaka. The mouth plays an important role in the threat sequence and presumably a large mouth would be advantageous.

Two forces could favor continued evolution toward a marked dimorphism. The adoption of the territorial habit possibly increased reproductive efficiency and reduced intraspecific competition. Ford (1951), Dobzhansky (1963), and Selander (1964) discussed the phenomenon of ecological polymorphism and the adaptive radiation possible within a population. If selection pressure favors size, including mouth size, would not the larger mouth size enable the male to take larger prey than before? If so, we would have the beginning of an expansion of the original species niche (presuming the male and female to have been closely monomorphic at one time in evolution).

One might now pose the question: how may niche expansion occur in the presence of a significant competing fauna? Hubb's (1961) and Hoese's (1964) studies of Nine Mile Pond describe it as being well represented with competing species. Perhaps at least

a partial answer may be gleaned from a re-examination of the habitat and dietary habits of *Microgobius*. Evidence from this and Ginsburg's (1934) study indicate that *Microgobius* is found in the bayou and coastal pond areas of the Gulf Coast. Such a habitat appears to be somewhat similar to the fresh water environment in that it is reasonably unstable as compared to more stable marine environments. Larkin (1956) in reference to the fresh water situation discussed the problem of plasticity in the fish fauna with characteristically broad food webs and ill defined ecological niches. Thus the environment of *Microgobius* may provide the necessary room for niche expansion.

Microgobius, as has been shown, has a rather broad range in diet. Size is essentially the only limiting factor as long as the prey is alive and moving. Plankton samples have shown that abundant prey is available in the size range which at present just exceeds *Microgobius's* capacity to eat. A possible opportunity for niche expansion may lie here.

The next question is, can and does this differential niche utilization occur? Results of the feeding experiments show conclusively that under laboratory conditions the male ingested food objects of significantly larger size than the female. More important, when natural food objects were used the males were able to ingest live prey which was too large for the female. It is significant that these food organisms were obtained from the natural habitat and at least a few were found by stomach analysis to be items of the natural diet. Problems of dominance, the difference in average size of the two sexes, number of each sex present, and other factors complicate the issue, but the fact remains that under aquarium conditions somewhat different niches were occupied by male and female.

Under present circumstances it is difficult to prove conclusively that in nature the sexes are utilizing different niches. The only population discovered in the area occupies a turbid habitat which precludes actual feeding observations. Stomach analysis is generally unsatisfactory for reasons stated above and because of the difficulty in measuring the size of partially digested food. Perhaps what is needed is a semi-controlled situation in which an area could be isolated and observations made. A clear water habitat which may exist in some areas would make detailed observations possible. Until this is practical, the controlled experiments in aquaria (described above) seem to be the only means of isolating the ecological significance of this phenomenon.

In the present case, the evidence indicates that *Microgobius* has most likely undergone niche expansion. The sexes probably occupy different, broadly overlapping, ecological niches. This is analogous to Selander's (1964) finding of differential niche utilization in melanerpine woodpeckers. The result could also be termed an over-all expansion of the species niche.

Summary

1. *Microgobius gulosus* is sexually dimorphic. Proportionately, the males have a much larger mouth than the females.
2. Under aquarium conditions males were found to be able to ingest larger food than the females. This was true both with artificial foods and that from their natural habitat.
3. Evidence, including morphological and behavioral aspects, indicates that *Microgobius* is carnivorous in eating habits, employing a wide range in diet.

4. Aggressive behavior, threat behavior, and territoriality are present in the behavioral makeup of *Microgobius*.
5. Niche expansion and differential niche utilization, by virtue of sexual dimorphism, have most likely occurred in *Microgobius*.

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Fauna of the Aransas Pass Inlet, Texas. I. Emigration as Shown by Tide Trap Collections[1]

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Abstract

A tide trap was used to sample the animals in the Aransas Pass Inlet, Texas. The net was lowered three days per week at maximum flood and ebb tides during the period between 15 April 1963 and 15 April 1964. About 24 species of invertebrates and 55 species of fishes were collected with the tide trap during the study.

Total catch of all organisms was greatest in May–June and in October. These large peaks were concomitant with the change in water level of the bays and changes in temperatures. Most organisms were caught on ebb tide, indicating a mass emigration of animals from the shallow productive nursery areas. Only *Anchoa* spp. were consistently caught during flood tides. Six species of invertebrates and 11 species of fishes were considered to be common emigrants and were caught in the tide trap in large numbers. All of these organisms demonstrated definite patterns in their emigration habits.

Computations showed that the net productivity of the bays as shown by tide trap collections was 233 kg/acre per year. About 3.9×10^6 kg/year of late juvenile penaeid shrimp emigrated through the Aransas Pass Inlet.

Introduction

Although several surveys of the fauna of the immediate area have been made, no one studied the importance of the Aransas Pass Inlet in the movement of animals between the shallow bays and the Gulf of Mexico. Gunter (1945) reported the fish fauna of Aransas and Copano Bays and the Gulf of Mexico. Gunter (1950) studied the seasonal distribution of invertebrates of the Texas coast and discussed this relationship with salinity. Hedgpeth (1953), Whitten, Rosene and Hedgpeth (1950) discussed the invertebrate fauna of the Gulf of Mexico, Aransas and Copano Bays and for the Aransas Pass Inlet Jetties, respectively. Hildebrand (1954) reported the fauna associated with the brown shrimp grounds of the Gulf of Mexico outside the 15 fathom contour. Miller (1965) discussed the fishes from a trawl study in the shallow (3 to 15 fathoms) Gulf of Mexico. Invertebrates from the area of 3 to 15 fathoms in the Gulf of Mexico adjacent to the Aransas Pass Inlet are being studied by Copeland and Miller (IMS, Personal Communication). Copeland and Truitt (1965) reported the annual pattern of migration of post-larval penaeid shrimp from the Gulf into the bay nursery grounds and discussed the importance of the Aransas Pass Inlet in that respect.

The data reported herein are the results of a year's study of the emigration of animals through the Inlet by means of tide trap collections. The study was conducted during the period between 15 April 1963 and 15 April 1964, in the Aransas Pass Inlet, Texas (Fig. 1).

[1] With the financial support of the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Contract #14-17-0002-51.

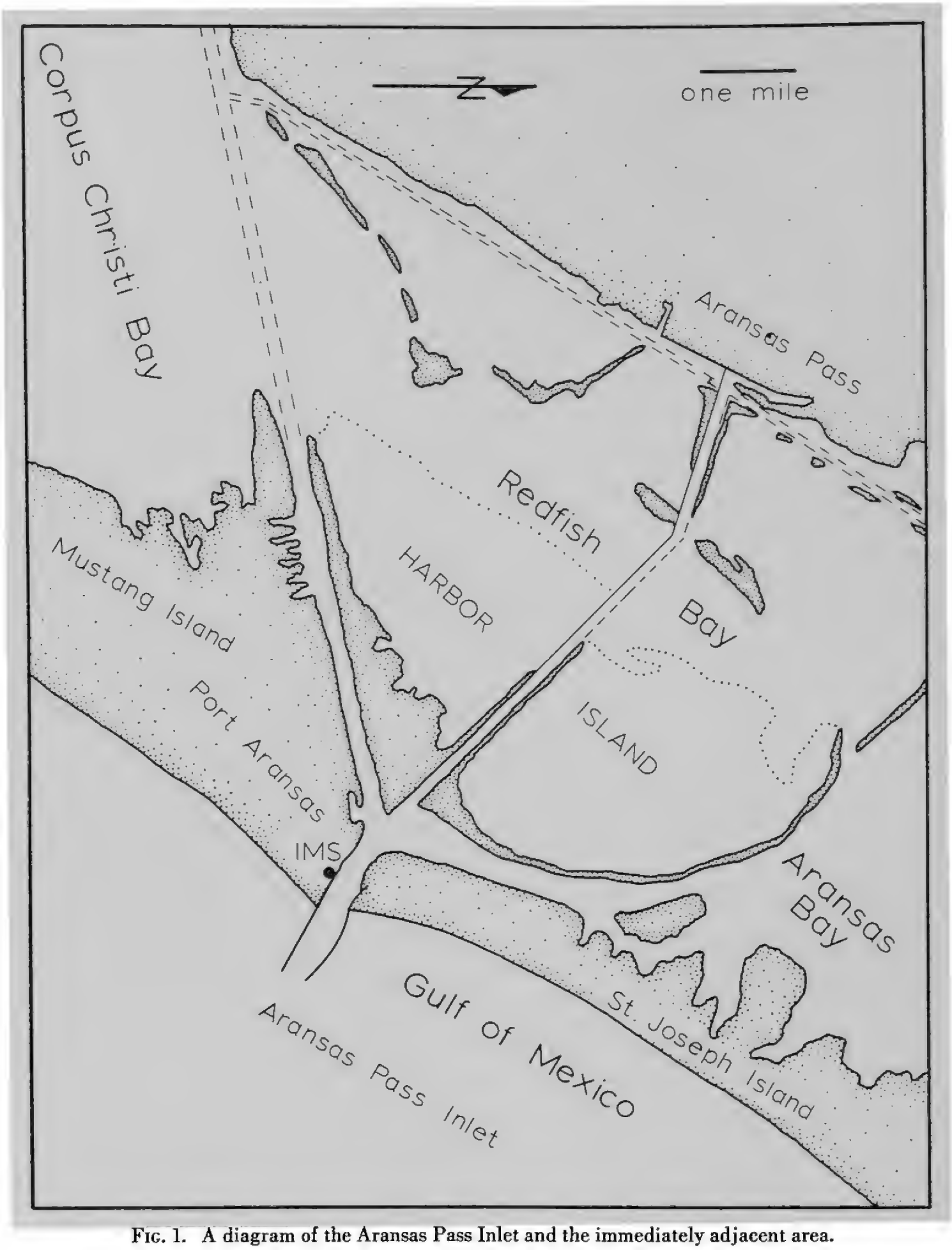

FIG. 1. A diagram of the Aransas Pass Inlet and the immediately adjacent area.

Methods

The tide trap was a net 1.59 m deep and 2.25 m wide, composed of ½-inch stretch nylon mesh for the first 6 m, with ¼-inch nylon mesh for the remaining 2 m. It was mounted underneath the pier laboratory of the Institute of Marine Science and raised and lowered by sliding the net on two parallel pipes secured vertically to the pier.

The tide trap was lowered three days per week at the time of maximum flood and ebb currents, regardless of night or day. The time that the net was in the water depended on the speed of the current and amount of animals being taken; i.e., 5 minutes during currents of 2 knots or more and 15 minutes during currents of less than 1 knot. The net usually fished at about mid-depth (about 3–5 m). The catch was counted and wet weighed immediately following capture.

An aluminum current drag was used to measure the current speed. The length of time required to pay out 10 m of line was recorded with the aid of a stop watch. Friction while paying out the line was considered negligible since some slack was allowed in the line between the current drag and the ring through which the line was run. A float was placed on a line about 1 m above the current drag so that the drag was well under the surface of the water and away from the influence of winds. The float was just under the water surface.

Current speed and time that the tide trap was in the water determined the volume of water that had passed through the tide trap. This was computed by multiplying the area of the tide trap opening in square meters by the time lowered in seconds and by the current speed in m/sec.

Temperatures and salinity were measured twice each month in conjunction with a simultaneous study on the migration of penaeid shrimp and are reported in a previous paper (Copeland and Truitt, 1965).

Results and Discussion

More than 24 species of invertebrates and 55 species of fishes were collected with the tide trap during the annual study. These data are presented in Fig. 2 and Tables 1 and 2. It should be noted that species other than those reported herein were known to be present in the area.

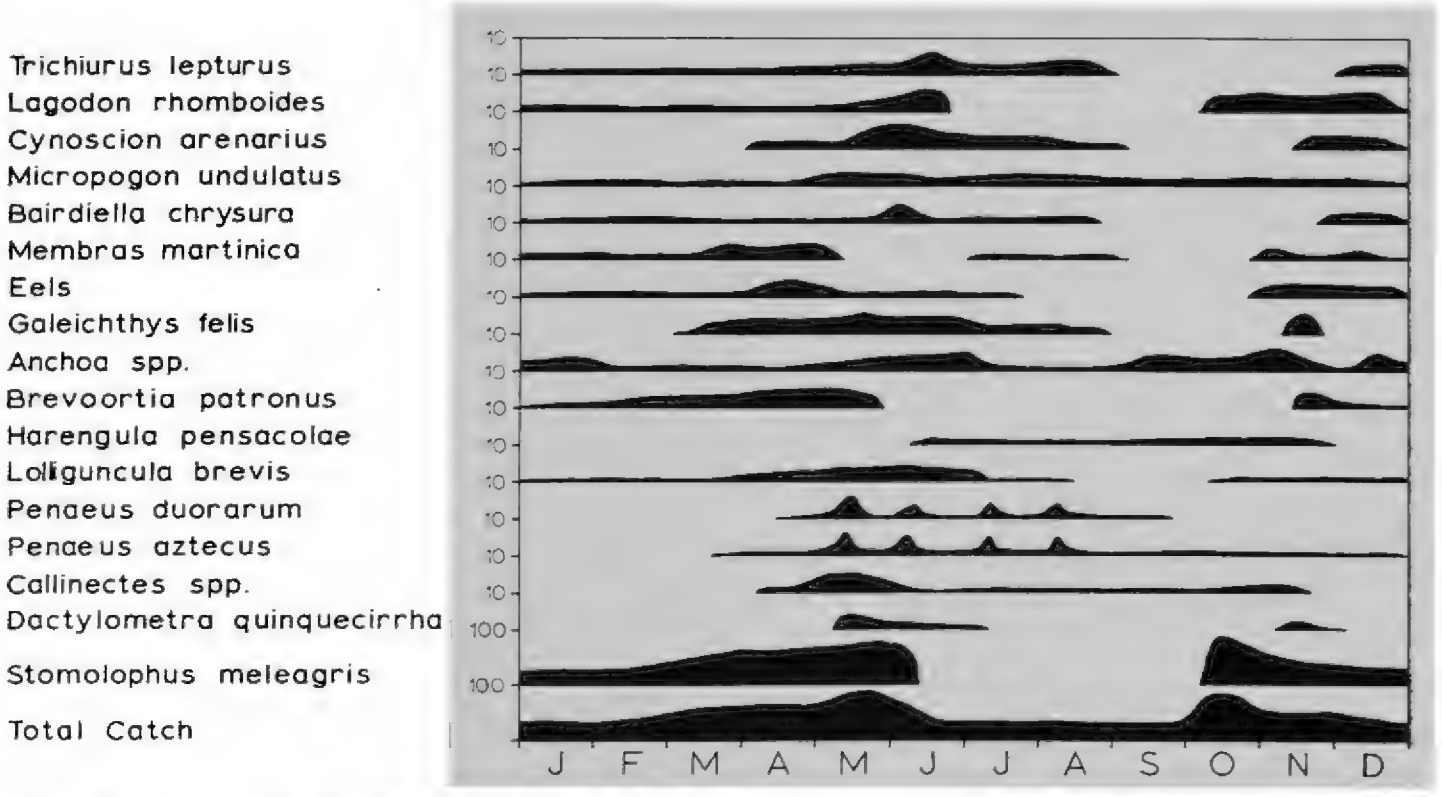

FIG. 2. Biomass in gm/m³ wet weight of animals caught during ebb tide in the Aransas Pass Inlet, April 1963–April 1964. The vertical scale is logarithmic.

Total Catch

Total catch consisted of everything caught in the tide trap and is presented in Fig. 2. Since most of the animals collected were on ebb tide, the following discussion is limited to ebb-tide collections. Total average catch was less than 1 gm/m^3 during January, February, July, August, and September; between 1 and 10 gm/m^3 during March, November and December; and between 10 and 100 gm/m^3 during April, May, early June and October. The large peaks in the curve are a reflection of *Stomolophus meleagris,* to be discussed later. The abundance of other animals also affected the shape of the curve, but in lesser amounts.

Hoese and Jones (1963) reported low-water periods for Redfish Bay during summer and winter. The two peaks in emigration from the bays shown in Fig. 2 correspond in time to just before the water level in the bay began to decrease. In other words, during times of low water levels in the bays, the amount of emigration out of the bays was low. This may mean that the level of water in the bay habitat was at least partly responsible for the emigration of animals from the bays.

Another factor could be temperature. During times of low and high temperatures emigration was least. Peak emigration occurred when the temperature was just beginning to reach a maximum and/or minimum.

Common Emigrants

The cabbagehead jellyfish, *Stomolophus meleagris* L. Agassiz, was by far the most prominent animal in the tide trap collections. A biomass of 95 gm/m^3 was often encountered. As shown in Fig. 2, the abundance of *S. meleagris* was highest during May and October. The emigration of *S. meleagris* ended about 10 June and began about 3 October, although they were known to be present in large numbers in the upper bay region. The abundance was 1 gm/m^3 during the latter part of December, during January, and early February; between 1 and 10 gm/m^3 during March, April, November and December; and, between 10 and 100 gm/m^3 during May and October.

An interesting correlation is the couplnig of the stopping and starting of *S. meleagris* emigration with the presence of 25 C water in Aransas Pass Inlet. Water temperature had increased to 25 C just as emigration stopped in June and had decreased to 25 C just as emigration started in October. Warmer water, however, did not seem to affect their presence in the upper bay regions during summer.

The sea nettle, *Chrysaora=Dactylometra quinquecirrha* (Desor), was collected during the period of May through June and during November (Fig. 2). Abundance was fairly low, never more than 0.5 gm/m^3. The greatest abundance occurred during May, decreasing to less than 0.1 gm/m^3 during June. A small peak was observed in November following the first "blue norther" of the season. Gunter (1950) found this species in the shallow Gulf in summer and fall, which correlates with the emigration out through the Pass in early summer shown by my data.

Callinectes spp. were commonly captured in the tide trap from 1 April until the last of November (Fig. 2). Their peak abundance was during late April and May, with a biomass as much as 5 gm/m^3. During the remainder of their emigratory time the biomass was usually less than 0.1 gm/m^3. Identification of the species of *Callinectes* was uncertain, therefore, all specimens are lumped under the genus name only. However, it was felt that almost all of them were *C. sapidus,* especially during peak.

A large number of *Callinectes* spp. taken during the peak movement were females carrying large egg masses. Large numbers of crab larvae were subsequently taken in plankton samples taken during June and July. Gunter (1950) reported more blue crabs in spring and early summer than during other times. Daugherty (1952) found that there was a gulfward movement of blue crabs through Cedar Bayou from March to July, corresponding to my data. Hildebrand (1954) also reported similar results. Hoese and Jones (1963) stated that a peak abundance of blue crabs occurred in Redfish Bay during March and early April, just before the peak emigration through the Pass during April and May (Fig. 2).

The brown shrimp, *Penaeus aztecus* Ives, was collected in the tide trap during 10 March 1963 through 31 December 1963 (Fig. 2). Their peak abundance, sometimes as much as 8 gm/m^3, usually occurred during the time of full moon in May, June, July and August. Although the data are not shown, the same phenomenon occurred during the summer of 1964. Apparently the high tides and faster currents that accompanied the time of full moon was enough to trigger the movement of these shrimp from the bay nursery grounds to the Gulf breeding areas. Another factor may be that the maximum ebb tides occurred at night during the time of full moon, but they also occurred at night during new moon.

The pink shrimp, *Penaeus duorarum* Burkenroad, occurred in the same pattern as *P. aztecus*, except that they were collected only during April through September. Furthermore, the peaks of *P. duorarum* were smaller than those of *P. aztecus*.

The length-frequency index for three catches of brown and pink shrimp are presented in Fig. 3. The number of shrimp was small for the 6–9 May pink shrimp curve, therefore the shape of the curve and validity are questionable. In all other plots the number of shrimp exceeded 200.

It is evident from the data in Fig. 3 that late juvenile and subadult shrimp emigrated through the Aransas Pass Inlet at about the same size regardless of whether it was May or June. Although the numbers were not large enough to make adequate plots, the same length-frequency was observed through September. The majority of the brown shrimp emigrants had a total length between 70 and 80 mm, with a slight skew to the right in the 1964 samples. The pink shrimp emigrants were mostly between 70 and 90 mm.

Hoese and Jones (1963) reported high bay populations of pink shrimp in Redfish Bay before emigrations began to occur through the Aransas Pass Inlet. Gunter (1950) showed roughly the same thing for brown shrimp in Aransas Bay. Copeland and Truitt (1965) reported post-larvae entering the pass in April through November.

The common bay squid, *Lolliguncula brevis* Blainville, was commonly captured in the tide trap except in August and September (Fig. 2). The greatest abundance occurred during April through June, with a biomass as much as 0.1 gm/m^3. They usually occurred in amounts of about 0.05 gm/m^3 or less.

Gunter (1950) and Hildebrand (1954) found this squid to be the most common in inshore waters. Gunter (1950) stated that they were common in the lower bays except in winter when the entire population moved out to sea. I found them moving out the Aransas Pass Inlet during all times of the year except early fall.

Two clupeids, *Harengula pensacolae* Goode and Bean (the sardine) and *Brevoortia patronus* Goode (the menhaden), were commonly taken in the tide trap during certain times of the year (Fig. 2). *H. pensacolae* was caught during June through November, at

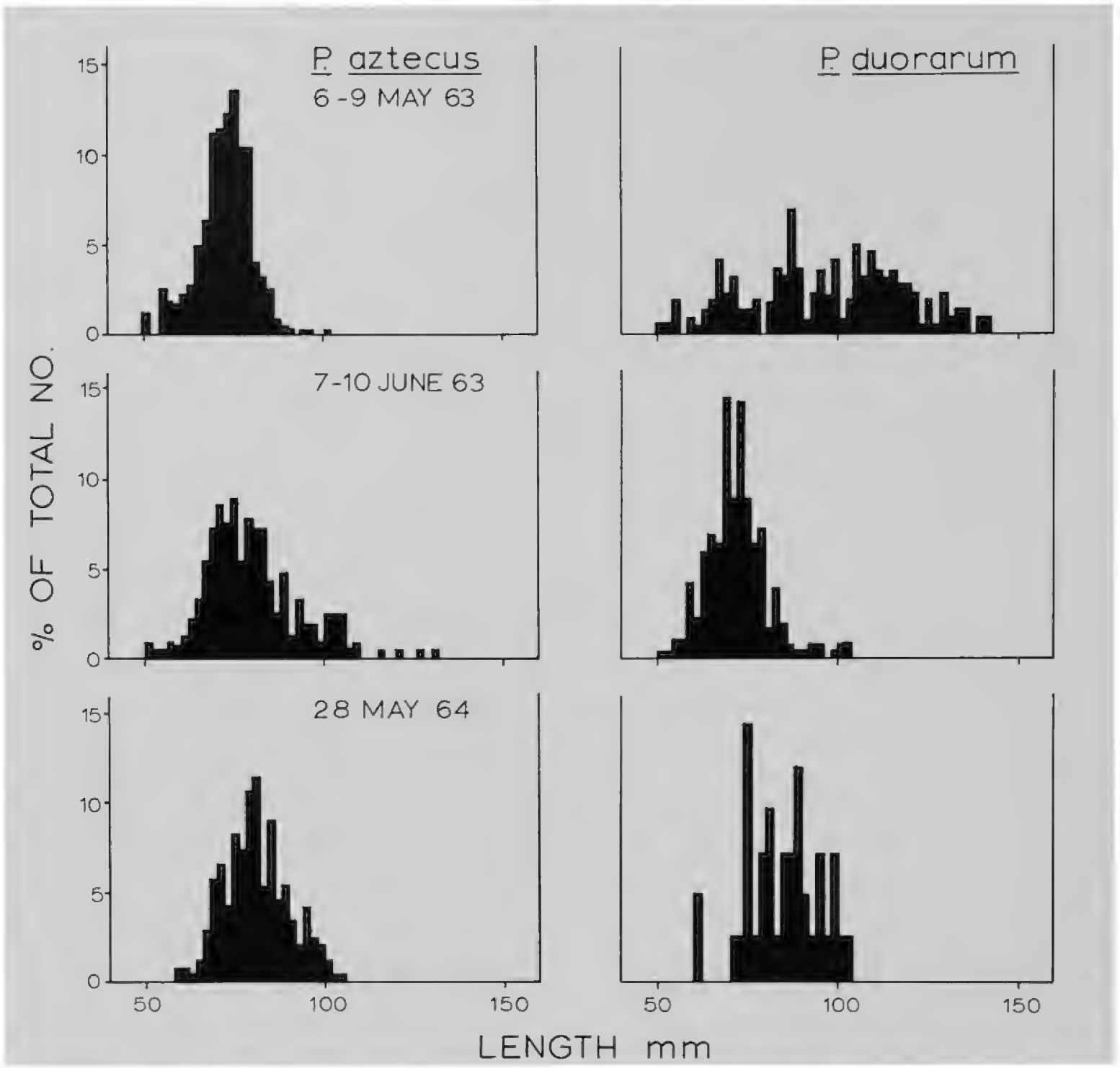

FIG. 3. Length frequency of *Penaeus aztecus* and *P. duorarum* captured at ebb tide in the Aransas Pass Inlet, May and June 1963 and May 1964.

a biomass value of less than 0.1 gm/m^3. Gunter (1945) did not take specimens during December through March. Springer and Woodburn (1960) found *H. pensacolae* to be abundant in the Tampa Bay area in summer and fall months.

B. patronus was caught during November through May, with peak emigration occurring in November and March through May. Springer and Woodburn (1960) observed this species in great abundance in the Tampa Bay area during February through May. Suttkus (1956) stated that *B. patronus* spawned off the Louisiana coast during October through February. This may account for the larger emigration out in November, as shown in my data. Gunter (1945) indicated a general absence of this species in Aransas and Copano Bays during mid-winter to early spring, and also indicated that spawning occurred during the same period.

The genus *Anchoa* (anchovies) was one of the two that were collected in the Pass during the entire year (Fig. 2). No attempt was made to distinguish between *A. hepsetus* (Linnaeus) and *A. mitchilli* (Valenciennes). Peak emigration was observed during

early summer and fall, with a biomass sometimes as much as 1 gm/m^3. Biomass during spring and late summer was usually less than 0.1 gm/m^3. Gunter (1945) reported *A. mitchilli* to be extremely abundant in the bays in this vicinity. Miller (1965) found *Anchoa* spp. in the shallow Gulf during his entire study (February through June).

The sea catfish, *Galeichthys felis* (Linnaeus), was caught at ebb tide during March through August with one small peak in November (Fig. 2). Average biomass was about 1 gm/m^3 during the November peak and slightly less than that during the spring and summer emigration. Eggs and young were observed in the mouths of the males during June through August. Gunter (1945) reported an increase of *G. felis* in the Gulf in November with very few collected during December through early summer. He further noted their high abundance in the adjacent bays during spring and summer. Hildebrand (1954) reported *G. felis* to be uncommon in the shallow Gulf during winter, common along the beach in summer, and very few along the beach during October. McFarland (1963) reported this species to be an all year resident in the surf zone outside the Pass. Miller (1965) found this species during the length of his study in only 3 to 6 fathoms.

The eels reported in this paper are of three species and no attempt was made to separate them. According to Mr. H. D. Hoese (Personal Communication), the eels consisted of *Myrophis punctatus* Lutken (very common), *Ophichthus gomesii* (Castelnau) (uncommon) and *Neoconger mucronatus* Girard (rare). This conclusion is based on random sampling of the portion of the catches that were saved or were observed personally by Mr. Hoese. Eels were commonly caught at ebb tide during mid-October through July (Fig. 2). The peak emigration was observed in April–May and during October–December, with a biomass exceeding 0.1 gm/m^3 during those times. Biomass during the remainder of the emigration was always less than 0.1 gm/m^3. Neither Gunter (1945) nor Hildebrand (1954) reported a large number of eels. However, the mesh size of the nets used by these authors would prohibit the capture of such a slender creature.

The rough silversides, *Membras martinica* (Cuvier and Valenciennes) was caught during November through April and in July and August (Fig. 2). Peak emigration occurred in March and April, with small peaks in November and December, following northers. Biomass exceeded 0.1 gm/m^3 during peak exodus, but was usually less than that. Gunter (1945) reported their breeding season to be during the spring, which corresponds to the largest emigration out the Pass as shown in my data. He did not report them from the Gulf. Hildebrand (1954) did not report *M. martinica* in his study of the brown shrimp grounds of the Gulf. Hoese and Jones (1963) did not report this species in the grassflats of adjacent Redfish Bay.

The silver perch, *Bairdiella chrysura* (Lacepede), was caught in the tide trap during late November through August (Fig. 2). Biomass was usually less than 0.1 gm/m^3, except during the last of May and first of June when biomass exceeded 0.1 gm/m^3. Hildebrand (1954) did not report this species in his study of the brown shrimp grounds of the Gulf of Mexico. However, Gunter (1945) reported it as a common inhabitant of the adjacent bays during all months. Miller (1965) collected only one specimen in the shallow Gulf.

The Atlantic croaker, *Micropogon undulatus* (Linnaeus), was collected during ebb tide through the entire year (Fig. 2). Biomass values were about the same (usually

less than 0.1 gm/m^3) with a slight increase during May through August. Gunter (1945) discussed the great abundance of this species on the Texas coast and indicated that they were most abundant in the bays during spring and more abundant in the Gulf during summer. These observations correlate well with the emigration pattern noted in the present study. Hildebrand (1954) stated that they were more abundant offshore during summer. Surprisingly, Hoese and Jones (1963) did not report this species from their Redfish Bay study area. Miller (1965) collected *M. undulatus* throughout his study, with peak abundance occurring in May and June.

The sand seatrout, *Cynoscion arenarius* Ginsburg, was caught in the tide trap during April to mid-September, and in November and December (Fig. 2). Biomass varied between 0.1 and 1 gm/m^3 during late May and early June, but generally less than 0.1 gm/m^3 during the remainder of the emigration. Gunter (1945) stated that this species was a common inhabitant of the bays of this area. Hildebrand (1954) contends that *C. arenarius* has a long breeding season that is concentrated during the fall. This corresponds with the outward emigration during the summer, since these fish presumably spawn outside the barrier islands. Miller (1965) collected this species in the shallow Gulf throughout his study.

The pinfish, *Lagodon rhomboides* (Linnaeus), was captured in the tide trap during October through June (Fig. 2). Emigration peaks occurred during the fall and in June, with biomass sometimes exceeding 1 gm/m^3. Biomass was generally less than 0.1 gm/m^3. Gunter (1945) discussed the yearly population fluctuations of pinfish and indicated their relative absence from the bays in winter. This corresponds with my emigration data (peak emigration in late fall and winter). Gunter also stated that the abundance of pinfish in the bays was greatest during August and September, corresponding with the data shown in Fig. 2 when no emigration occurred during that time. Presumably that is when the young are most prevalent in the bay regions. They apparently spawn in winter in the Gulf, which accounts for the larger emigration during late fall (Gunter, 1945). Hoese and Jones (1963) reported a peak abundance of pinfish in Redfish Bay during May and September, which are just before the peak emigration through the pass in June and October-November (Fig. 2). Miller (1965) found this species in the shallow Gulf during the same period as their emigration as shown in Fig. 2.

The Atlantic cutlassfish, *Trichiurus lepturus* Linnaeus, was caught during December through August (Fig. 2). Peak emigration occurred during the summer, June through August. Hildebrand (1954) reported this species to be most abundant in the shallow Gulf during the months of June and July, corresponding with the peak emigration shown in my data. Miller (1965) reported small (20 to 40 mm) cutlassfish in his trawl survey of the shallow Gulf during summer (May and June), indicating spawning may occur at that time. He also reported the presence of adults throughout his study (February through June).

Occasional Emigrants

Many animals were collected in the tide trap in erratic concentrations and will be reported herein as occasional emigrants. These data are presented in Tables 1 and 2. The more common members of this category are presented on a monthly basis in Table 1 and

TABLE 1

Monthly catch of common emigrants in the tide trap during ebb tide in the Aransas Pass Inlet. Each number indicates the total number of each species caught during the entire month

Species	J	F	M	A	M	J	J	A	S	O	N	D
Mysis stenolepis	....	....	....	....	....	104	17	15	....	....	....	....
Squilla empusa	....	....	1	....	....	1	32	31	75	....	1	9
Trachypeneus similis	2	7	....	6	....	3	546	137	....	....	....	....
Hyporhamphus unifasciatus	....	....	14	7	1	....	11	8	....	104	304	10
Chloroscombrus chrysurus	....	3	....	....	....	....	....	....	....	45	46	19
Oligoplites saurus	20	....	....	....	....	....	....	....	....	4	8	2
Hemicaranx amblyrhynchus	1	5	....	....	....	....	....	....	....	13	2	17
Poronotus triacanthus	....	2	1	47	10	....	....	....	....	....	5	10
Porichthys porosissimus	....	....	....	....	2	42	16	1	....	....	1	....

will be discussed separately. The rare members of the occasional emigrants are presented on a seasonal basis in Table 2 and will be discussed as seasonal groups.

One hundred and thirty-six specimens of *Mysis stenolepsis* (Smith) were collected during ebb tide, all during the months of June through August (Table 1). The greatest abundance was in June when the water level in the bays was beginning to decrease. Gunter (1950) and Hildebrand (1954) did not report this species in their studies, but the mesh-size of the net they used for collecting was too large to capture this small animal.

The mantis shrimp, *Squilla empusa* Say, was collected at ebb tide during most of the year, but were more concentrated during July through September (Table 1). Gunter (1950) collected this species in both the bays and shallow Gulf in June, October and November. Hildebrand (1954) mentioned the great abundance of this animal in the Gulf. Mr. H. D. Hoese and E. D. Lane, Institute of Marine Science (Personal Communication), collected large numbers of *S. empusa* in Aransas Bay during September, 1964, and remarked at their abundance in tide trap collections during that time.

Trachypeneus similis Smith was collected in the tide trap during January through August, with peak occurrence in July and August (Table 1). All of my specimens are believed to be *T. similis*, although Gunter (1950) reported mostly *T. constrictus* in the immediate area. It may be that the higher salinities in recent years has allowed *T. similis* to move into this area (Gunter says that they are restricted to salinities above 33 ppt). Hildebrand (1954) reported *T. similis* in the adjacent Gulf during November through August.

With the exception of June and September, the halfbeak, *Hyporhamphus unifasciatus* (Ranzani), were caught during March through December (Table 1). Peak emigration occurred during October and November. Gunter (1945) collected 4 specimens during his study of the adjacent area, all in August.

The bumper, *Chloroscombrus chrysurus* (Linnaeus), was collected during October through February (Table 1). Gunter (1945) reported that this species was common in adjacent bays and the Gulf during summer and fall. Hildebrand (1954) reported it during other times of the year and stated that it must be close to shore during the summer, as he did not collect it in the deeper water during that time.

The leatherjacket, *Oligoplites saurus* (Bloch and Schneider), was collected during October through January (Table 1). Gunter (1945) reported this species in Copano and Aransas Bays during the summer and in the Gulf during November. Hildebrand (1954) did not report it in deeper Gulf water.

The bluntnose jack, *Hemicaranx amblyrhynchus*, was collected during October through February (Table 1). Gunter (1945 as *H. rhomboides*) reported it from Aransas Bay during June through August. Hildebrand (1954) found them under the bell of the cabbagehead jellyfish in the Gulf during fall and winter. My data correlates well with these findings.

The butterfish, *Poronotus triacanthus* (Peck) was collected during November through May (Table 1). Hildebrand (1954) noted this species in greatest abundance in the Gulf during May through July, but took them all year. Most of the *P. triacanthus* reported by Gunter (1945) were taken in Aransas Bay in March.

All of the four last fishes discussed are known to be associated as juveniles with the cabbagehead jellyfish, *S. meleagris* (Hildebrand, 1954; Mansueti, 1963). Their appearance in the tide trap collections correspond to the emigration of *S. meleagris* through the Pass (compare Table 1and Fig. 2). *C. chrysurus*, *O. saurus* and *H. amblyrhynchus* appeared during the fall peak of *S. meleagris* emigration, while *P. triacanthus* appeared during the entire emigration of cabbagehead. It is not certain whether it is obligatory for these fish to remain with the cabbagehead at all times. However, the author has never noticed any of them except in the presence of *S. meleagris*.

The Atlantic midshipman, *Porichthys porosissimus* (Cuvier and Valenciennes), was collected during May through November (Table 1). Their greatest abundance, however, was during June and July, when over 90% of them were captured. E. D. Lane, Institute of Marine Science, who is currently working out the ecology and reproduction of this species has found them in large numbers in Aransas Bay during late summer and fall (Personal Communication). Gunter (1945) caught this species in Copano Bay in April and in Aransas Bay during July through November. Hildebrand (1954) noted large numbers of them in the Gulf but gave no seasonal data.

Rare to uncommon animals emigrating through the Aransas Pass Inlet are reported in Table 2 on a seasonal basis. Thirteen species of invertebrates and 37 species of fishes are included in this category.

Only three species were encountered during all seasons: the white shrimp, *Penaeus setiferus*; the spot croaker, *Leiostomus xanthurus*; and the harvestfish, *Peprilus paru*. *P. setiferus* was most abundant during summer and least abundant during winter. *L. xanthurus* and *P. paru* were also most abundant during summer, but their season of least abundance is somewhat vague.

Additionally, 24 species were collected during only one season. Most of them were observed only once or twice and conclusions on distribution could not be derived. In the case of a few species, however, sufficient numbers were collected for conclusions to be made. The lion's mane jellyfish, *Cyanea capillata* (Linnaeus), was observed only during the spring. Hoese, Copeland and Miller (1964) reported the presence of *C. capillata* in the Port Aransas area and discussed its seasonal occurrence. The sheepshead minnow, *Cyprinodon variegatus* Lacepede, was observed during the winter, when 45 specimens were collected. Their capture was generally concomitant with a "norther."

Finally, 17 species were collected during winter, 19 during spring, 29 during summer, and 24 during fall. The high number of species during summer is related to the large emigration of animals from the bay during June when the water level began to fall and water temperature became high. The large number of species during fall can be at-

tributed to the large emigration of animals during October, when the water level was again high and water temperature was relatively low.

Flood Tide Collections

The difference in catch between flood tide collections and ebb tide collections was tremendous. Few specimens were collected during flood tide, although the tide trap was

Table 2

Seasonal catch of rare emigrants in the tide trap during ebb tide in the Aransas Pass Inlet. Each number indicates the number of each species caught during the entire season.

Species	Winter (Dec-Feb)	Spring (Mar-May)	Summer (June-Sept)	Fall (Oct-Nov)
Cyanea capillata	....	4	....	....
Aurelia aurita	....	....	1	8
Polychaeta	....	2	....	....
Amphipoda	14	....	....	....
Isopoda	....	....	6	1
Libinia emarginata	4	....	....	3
Neopanopa texana	....	....	1	....
Palaemonetes vulgaria	....	....	2	....
Crangon sp.	....	....	....	30
Sicyonia sp.	....	....	14	....
Xiphopeneus kroyeri	....	....	....	2
Peneus setiferus	2	3	13	7
Aplysia sp.	....	....	1	....
Dasyatis sp.	....	1	....	....
Rhinoptera bonasus	....	....	1	....
Elops saurus	....	....	....	1
Opisthonema oglinum	....	....	1	....
Synodus foetens	....	....	23	3
Bagre marina	20	1	....	5
Strongylura sp.	1	3	1	....
Urophycis floridanus	....	3	....	....
Syngnathus sp.	1	....	....	6
Hippocampus zosterae	....	....	....	2
Cyprinodon variegatus	45	....	....	....
Mugil cephalus	20	....	3	....
Polydactylus octonemus	....	1	2	....
Pomatomus saltatrix	....	1	....	3
Vomer setapinnis	....	....	13	1
Caranx hippos	....	....	....	2
Eucinostomus argenteus	....	....	4	12
Orthopristis chrysopterus	1	....	6	....
Leiostomus xanthurus	1	1	6	1
Stellifer lanceolatus	....	12	9	1
Cynoscion nebulosus	1	....	....	....
Archosargus probatocephalus	1	....	....	....
Chaetodipterus faber	....	4	....	1
Astroscopus ygraecum	2	1	....	1
Brotula barbata	....	1	....	....
Scomberomorus maculatus	7	1	3	....
Peprilus paru	2	4	5	2
Gobies (*Gobionellus* & *Gobiosoma*)	....	1	3	....
Prionotus sp.	....	2	4	1
Citharichthys spilopterus	9	....	5	1
Paralichthys lethostigma	....	....	1	.
Ancylopsetta quadrocellata	....	....	7	4
Symphurus plagiusa	....	....	4	....
Sphoeroides nephelus	....	....	1	.
Lagocephalus laevigatus	6	....	1	2
Chilomycterus shoepfi	....	....	1	....
Histrio histrio	....	1	....	....

lowered for almost as many flood tide collections as ebb tide. Presumably the larvae and post-larvae migrating into the bays were too small to be collected in the tide trap.

The only species collected with any consistency during the entire year was *Anchoa* spp. The winter catch was low, with only occasional specimens collected.

Most of the other species discussed in the previous sections were collected at one time or another during flood tide. However, they were probably caught when the current reversed while the animals were still in the pass.

General Considerations

The amount of biomass leaving the shallow, highly productive bays of Texas into the Gulf of Mexico is almost unbelievable. If a tide trap catch immediately following a "blue norther" is used as an example, truly fantastic figures can be calculated. On 21 October 1963, 94.62 gm/m^3 of biomass was captured. That figure multiplied by the vertical area of the pass times the speed of the current (4730 m^2 × 0.787 m/sec or 3722.5 m^3/sec) yields 352.2 kg/sec biomass going through the pass. Of course, certain assumptions concerning the uniformity of organisms and uniformity of current over the entire pass must be considered. These calculations were made to give some scope to the amount of exchange between the important nursery grounds (bays) and the equally important breeding grounds (Gulf shelf). The catch used in the above example is considerably larger than normal but on the other hand, it was not the largest one ever made.

More realistically, the average current and biomass for each time the tide trap was lowered at ebb tide was computed and that average used for biomass calculations. The average current speed was 0.654 m/sec and average biomass was 7.16 gm/m^3. Application of these figures to the above relationship, a biomass of 22.15 kg/sec. was computed. Considering that ebb currents run at about the same speed over a period of 4 hours per day (or average that speed for a total of 4 hours during any one day) this figure then becomes 318,960 kg/day for a yearly average. More emphatically, the biomass produced in the highly productive bay area served by the inlet approximated 11.65 × 10^7 kg/year. Furthermore, this figure is considered to be a very conservative estimate.

If all the bay area south of San Antonio Bay and north of the Laguna Madre Land Cut are considered to be dependent upon the Aransas Pass Inlet for their connection to the Gulf, ½ million acres of bay are involved. The net productivity of these bays, using the above figures, was computed to be 233 kg/acre (576 kg/hectare) per year.

Since shrimp are of great commercial importance, similar computations have been made for the penaeid shrimp caught during ebb tide. About 3.9 × 10^6 kg/year (or 8.6 × 10^6 pounds/year) are estimated to have made their way from the bay nursery areas through the pass to the Gulf of Mexico.

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H. D. Hoese confirmed the identification of organisms. William Gillespie constructed the figures.

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A Study of the Hydrography of Inshore Waters in the Western Gulf of Mexico Off Port Aransas, Texas

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Abstract

A one-year study of the hydrography was conducted during 1962 and 1963 on a 25 nautical-mile transect running 112° from Port Aransas, Texas. Thermal stratification was found to exist approximately 50% of the time at most stations with turnover in October and March. Light penetration was an effective method of distinguishing water masses. Optical density profiles increased in slope near the bottom during summer, indicating more opaque water on the bottom. Gulf and coastal water masses were distinguished by the degree of inclination of optical density plots. An intermediate water mass, which may be a part of Gulf water, was detected within the range of the transect during both winter and summer. However, northers drove the line of demarcation more offshore on several occasions during winter. Offshore species of larval fishes were found inshore only when offshore water masses moved inshore.

Introduction

Most hydrographic studies along the Texas coast have been done on bays and estuaries (Collier and Hedgpeth, 1950) or on more distant offshore waters (Texas A and M Research Foundation Reports, 1952–1956; and Collier, 1958). Our study had two purposes: One was to study hydrography of inshore waters adjacent to the beach. The other was to investigate possible correlations between larval fish types and water masses.

A study was conducted on a transect running 112° magnetic from Port Aransas, Texas, from September 1962 to August 1963 (Fig. 1). Seven stations were established; one in the Aransas Pass channel, one almost onshore, and the remaining five at 5-nautical miles intervals out to 25 miles. Light penetration, temperature, salinity and density were considered as criteria for separation of water masses.

Curl (1959) conducted a similar investigation of the inshore Northeastern Gulf of Mexico near Alligator Harbor, Florida. He found the spatial relationship of coastal and Gulf waters to be about the same as found in this study. His investigation is the only one comparable to the present study in the Gulf of Mexico.

Gunter (1945), in his important work on the fish fauna of the western Gulf of Mexico, reported hydrographic data and described the area where the present study was conducted. He observed approximately the same range in temperature and salinity reported here. On numerous occasions, salinity and temperature inversions were observed, such as those to be discussed in the present work.

Clarke (1938) observed optical densities of one in 10 to 40 meters in the Gulf of Mexico. He found an increase in optical density near the bottom at some stations, as did we. This phenomenon was noted in both cases only during the summer months.

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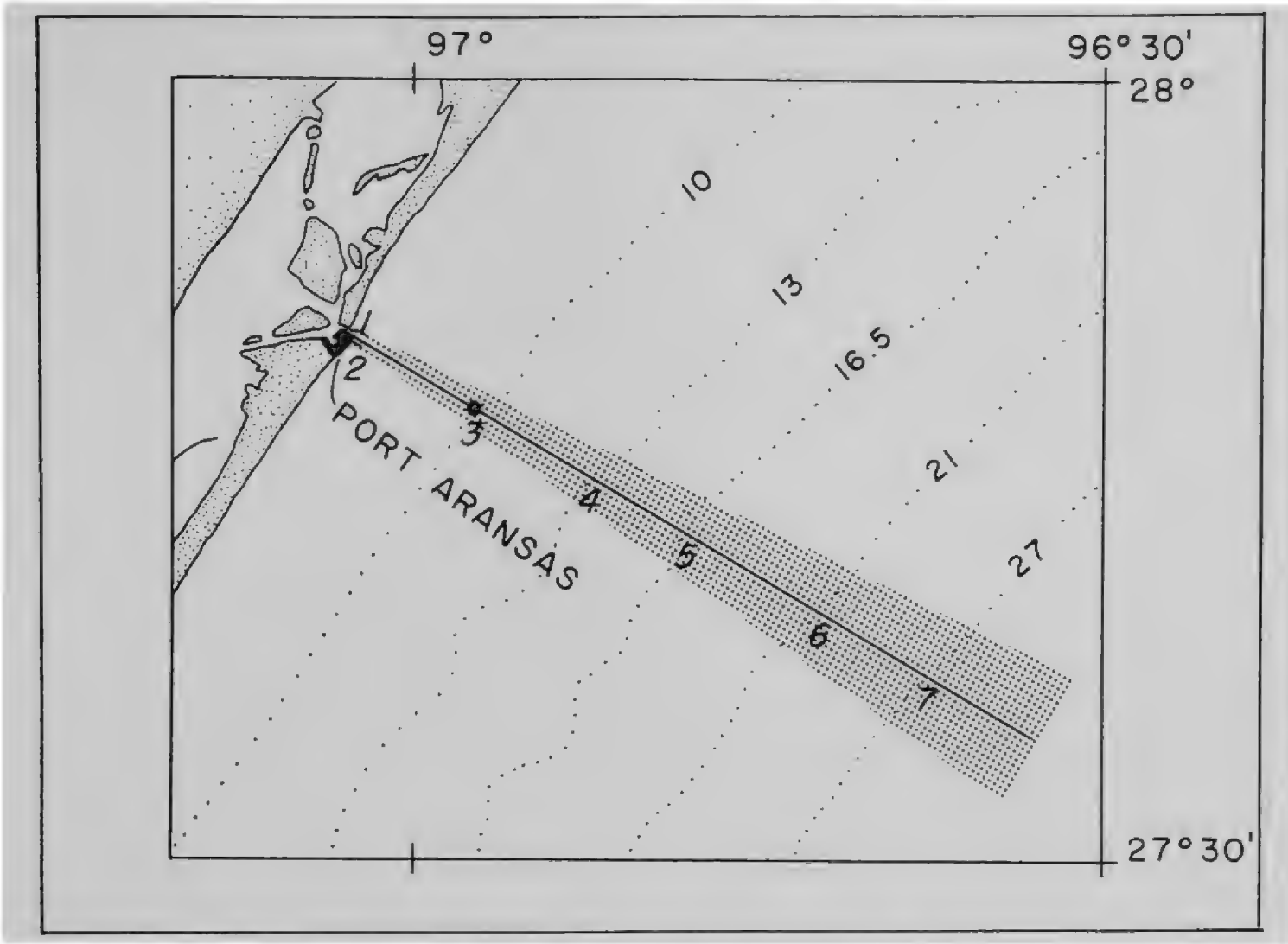


FIG. 1. Diagram of the sampling area showing station locations. The line indicates the transect and the stippled area indicates the area within navigation limits. The numbers on the dotted contour lines indicate the approximate depth at each station in fathoms.

Young and Gordon (1939) found optical densities of one in about 30 to 40 meters of water off the coast of California, about the same as found in the waters of the Gulf of Mexico.

Chew (1955) presented evidence of longshore currents in the region of the present study during summer. Kimsey and Temple (1963) found evidence of eddy areas and substantial longshore currents in the region of the present study. They further stated that current direction and velocity changed with depth and time of day. They found that currents as much as 48 nautical miles off-shore were influenced by tide and wind action. These observations may also account for some of the anomalies indicated in the following figures.

Methods

Samples of water were taken at each station (Fig. 1) at least once each month at 9 meter intervals in depth. Surface samples were also taken at mid-points between main stations.

Temperature was measured in the surface samples with a mercury-in-glass thermometer (0–50 C). Temperature profiles at each main station were taken with a 200-feet bathythermograph. The Mohr titrametric method (Barnes, 1959) was used to determine salinity. Water density (sigma t) was computed from U.S. Navy Hydrographic Office density tables (U.S. Navy, 1952), using temperature and salinity.

Light penetration was measured with a submarine photometer. Relative light intensity was measured at 2-meter intervals and correlated to the surface intensity. Optical density was computed as the logarithm of the ratio of intensity at a particular depth with intensity at the surface, as shown in equation (1).

$$\text{O. D.} = \log_{10} \frac{\text{surface intensity}}{\text{intensity at z}} \qquad (1)$$

Larval fish collections were made at night near the surface at each station with a one-meter plankton net. The net was dragged behind a boat for 15 minutes at a speed of approximately two knots. Larval fish were identified in the laboratory.

Results

Temperature Profiles

Temperature profiles are presented in Fig. 2. Heavy seas prevented the taking of BT readings at Station 7 on January 9, 1963. The BT was lost at sea on May 21, 1963, and readings were not taken at Stations 6 and 7 on that date.

Temperature varied more during the year at the inshore than at the offshore stations. A 35 F (20 C) difference occurred at Station 3 between September and February, while only a 17 F (10 C) difference occurred at Station 7 for the same time.

Thermal stratification was present at all stations except Station 3 on September 13, 1962. North winds in October and November upset thermal stratification and the water was isothermal at each station. Reverse thermoclines were observed at all stations in January and at the two inshore stations in February. In winter, north winds associated with periodic cold fronts blew across the study area and forced the less saline, cold bay water on top of the warmer, more saline Gulf water. The water was almost isothermal at each station during March and April with thermal stratification starting in Stations 5 through 7 in April. By May 21, thermal stratification was probably present at all stations. However, strong southeasterly winds in June eliminated stratification at Stations 3 and 4. With the onset of moderate winds in later months, stratification was again present at all stations in July. Furthermore, cold bottom water was present in the study area during the summer, encroaching to the inshore station (3) during May and July.

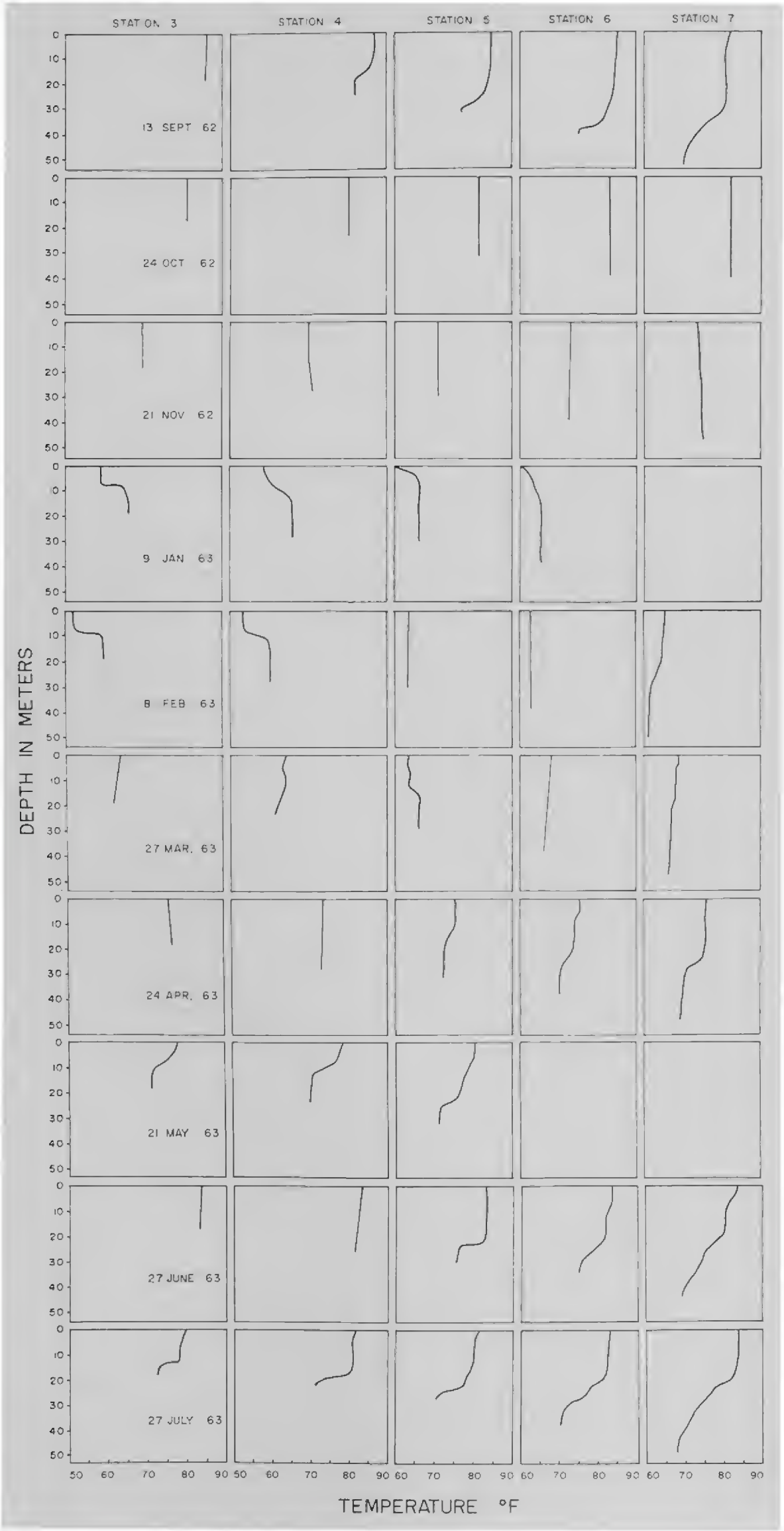
Thermal stratification existed more than 50% of the time and may have important effects on productivity and plankton. Spring and fall turnovers in conjunction with winter and summer "stability" possibly account for spring and fall peaks in productivity.

Salinity Sections

Isohalines are plotted in Fig. 3. Average salinity was generally high with a wide range in values.

From November through March, large differences between inshore and offshore salinities prevailed. In November the isohalines were almost vertical. Long-shore currents possibly accounted for the isolated higher salinities in the 10 to 18 mile interval of the transect. Strong north winds in January apparently blew the lower saline bay water out into the Gulf, causing the almost horizontal isohalines observed on January 9.

Fig. 2. Temperature profiles for Stations 3 through 7. The length of the profile line indicates station depth at each station.


STATION 3
STATION 4
STATION 5
STATION 6
STATION 7
13 SEPT 62
24 OCT 62
21 NOV 62
9 JAN 63
8 FEB 63
27 MAR. 63
24 APR. 63
21 MAY 63
27 JUNE 63
27 JULY 63
DEPTH IN METERS
0
10
20
30
40
50
50 60 70 80 90
TEMPERATURE °F

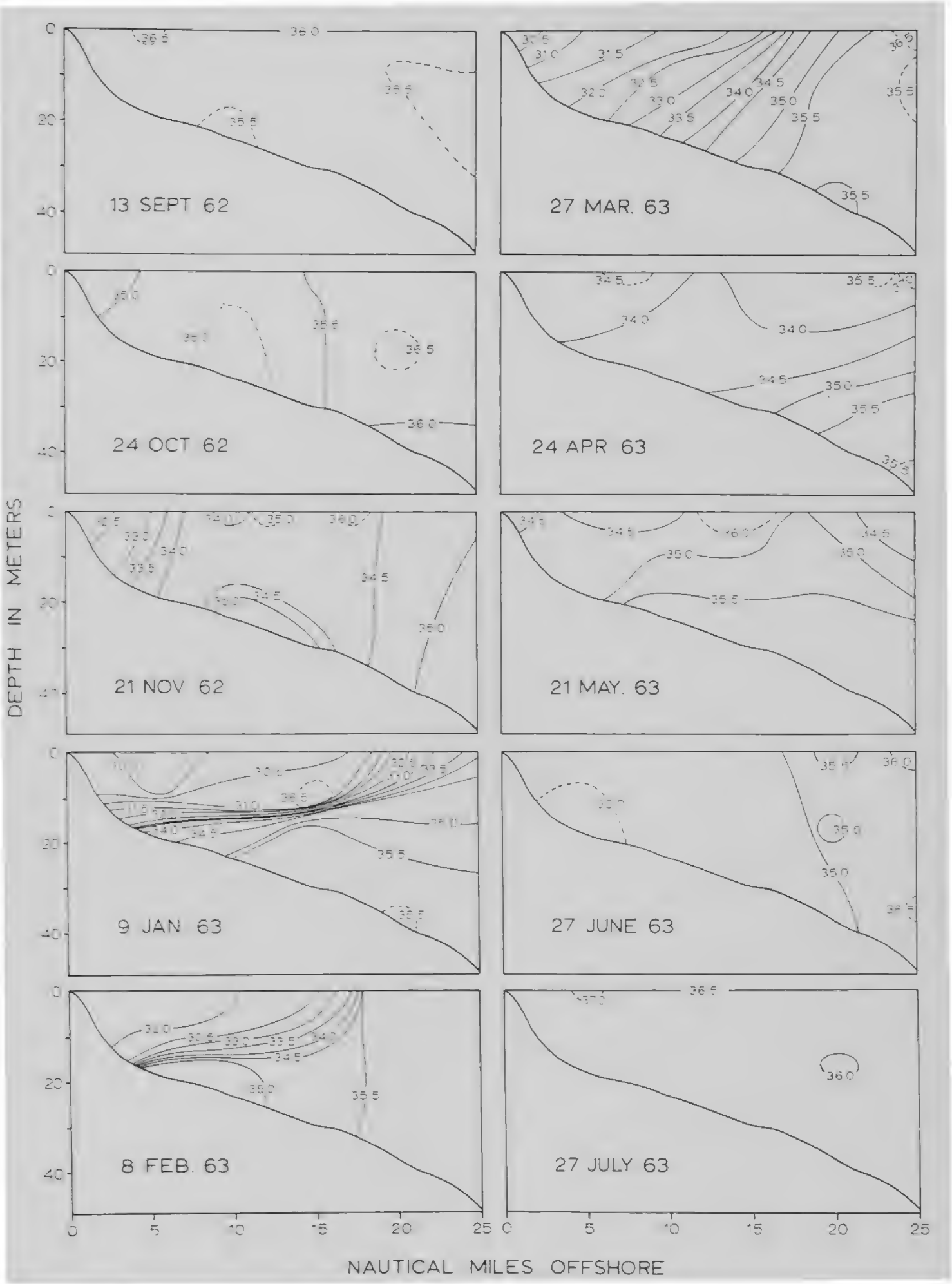


FIG. 3. Salinity profiles for the sampling area. Dashed line indicates salinity anomalies.

Two distinctly different salinity regimes existed on February 8; an offshore one of 35 to 36 ppt and an inshore one of 32 to 32.5 ppt. Narrow, gently sloping salinity layers existed on March 27 and the range between values was large.

The sections for April and May show a condition which frequently occurs in this re-

gion. A slick indicating a convergence line was encountered about 13 miles offshore in April and 18 miles offshore in May. In April, 34.5 ppt water was bounded on both the offshore and inshore sides by 34.0 ppt water, while in May the relationship was 1.0 ppt higher. The slick was observed to continue at right angles to the transect.

During June and July of 1963 and September of 1962, the water was almost homogenous with respect to salinity. Less than 1 ppt difference existed between the shore and the end of the transect. Some differentiation was observed in October of 1962. However, the salinity gradient was still rather small.

Density Sections

Water density (sigma t) was computed from salinity and temperature data and plotted in Fig. 4. The lowest sigma t, encountered on September 28, 1962 at an onshore station, was 17.5. The highest sigma t (26.0) was encountered in January, February and July, at offshore stations. In general, density increased in the offshore direction. On a few occasions, upwellings of dense water between or above masses of less dense water were observed, as seen during May and July. During all months except October and November dense bottom water moved inshore under lighter water. In May–September this was caused by cold water and in the remainder by high salinity water.

Light Penetration

Optical densities at Station 2 through 7 are graphed in Fig. 5. Average extinction coefficients could be calculated from the optical density data by merely dividing the depth in meters at which an optical density of one (10% surface illumination) occurred into 2.3 (Sverdrup, Johnson and Fleming, 1942: 82).

Transparency seemed to be about equal with reference to depth at most stations. However, the curving downward of the optical density profiles show turbid waters were present near the bottom of nearly all stations during May, June and July, associated with denser water on the bottom. Yet, this water is the high density water presumably from offshore origin. Other possibilities include enough current along the bottom to keep sediments suspended, or cold bottom water intrusions from the north and the Mississippi River.

Density sections (Fig. 4) and temperature profiles (Fig. 2) indicate that this water mass was from offshore. Kimsey and Temple (1963) discussed current systems in inshore waters and indicated the presence of bottom currents that may be strong enough to keep sediments suspended. As for the cold turbid water coming from the Mississippi River, longshore currents do flow in a southerly direction during summer, accounting for the turbidity in summer only.

The differences in the slopes of the optical density versus depth lines between stations may be used to distinguish water masses. These differences will be discussed below.

Distribution of Larval Fishes

Even though analyses of larval fishes are incomplete, the major elements in the fauna are apparent. Inshore and offshore spawning species were recognized and some of these were found strictly in the coastal or Gulf water masses delimited by other methods.

In May through July, *Anchoa hepsetus* and *Harengula pensacolae* predominated in

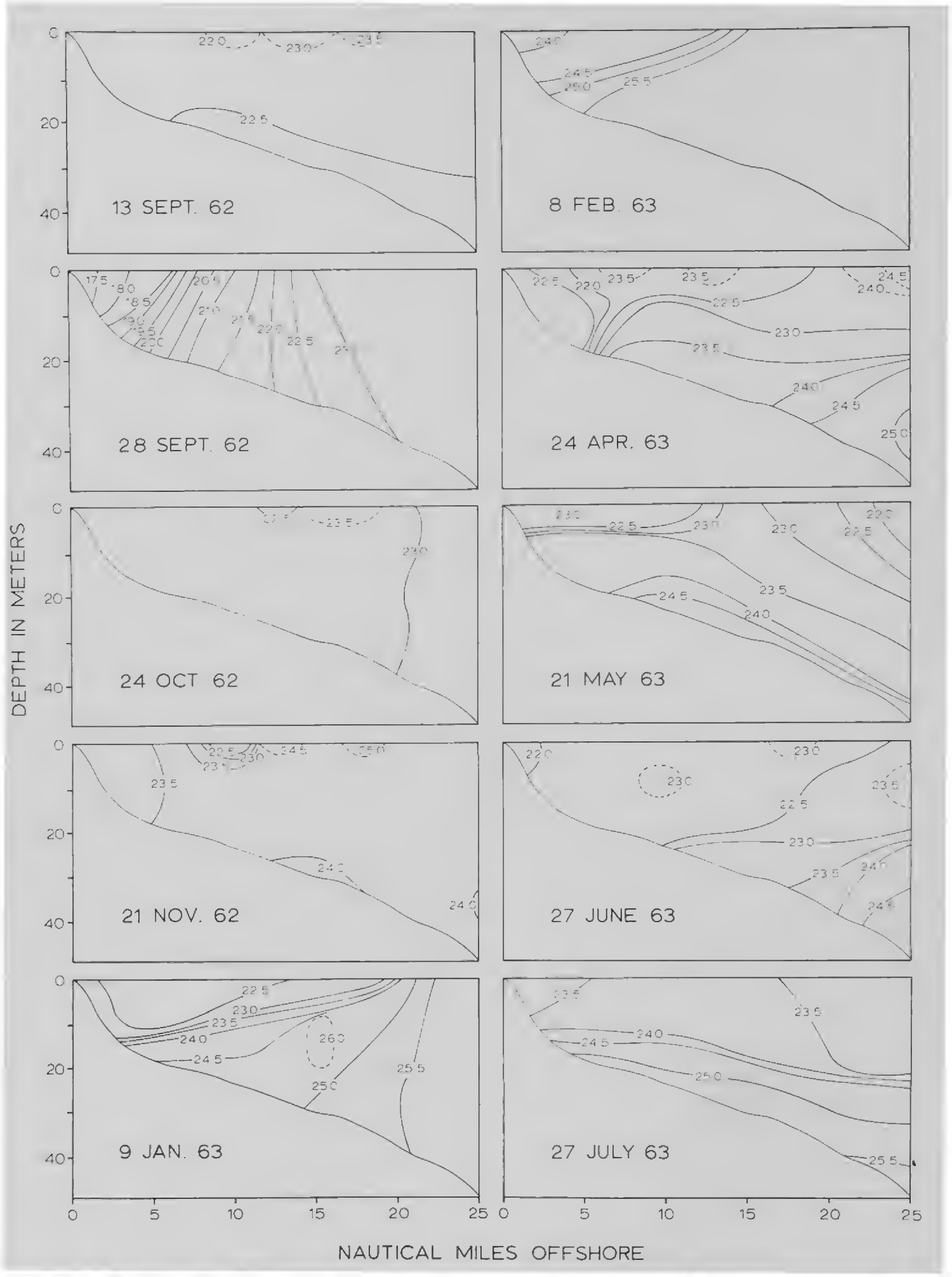
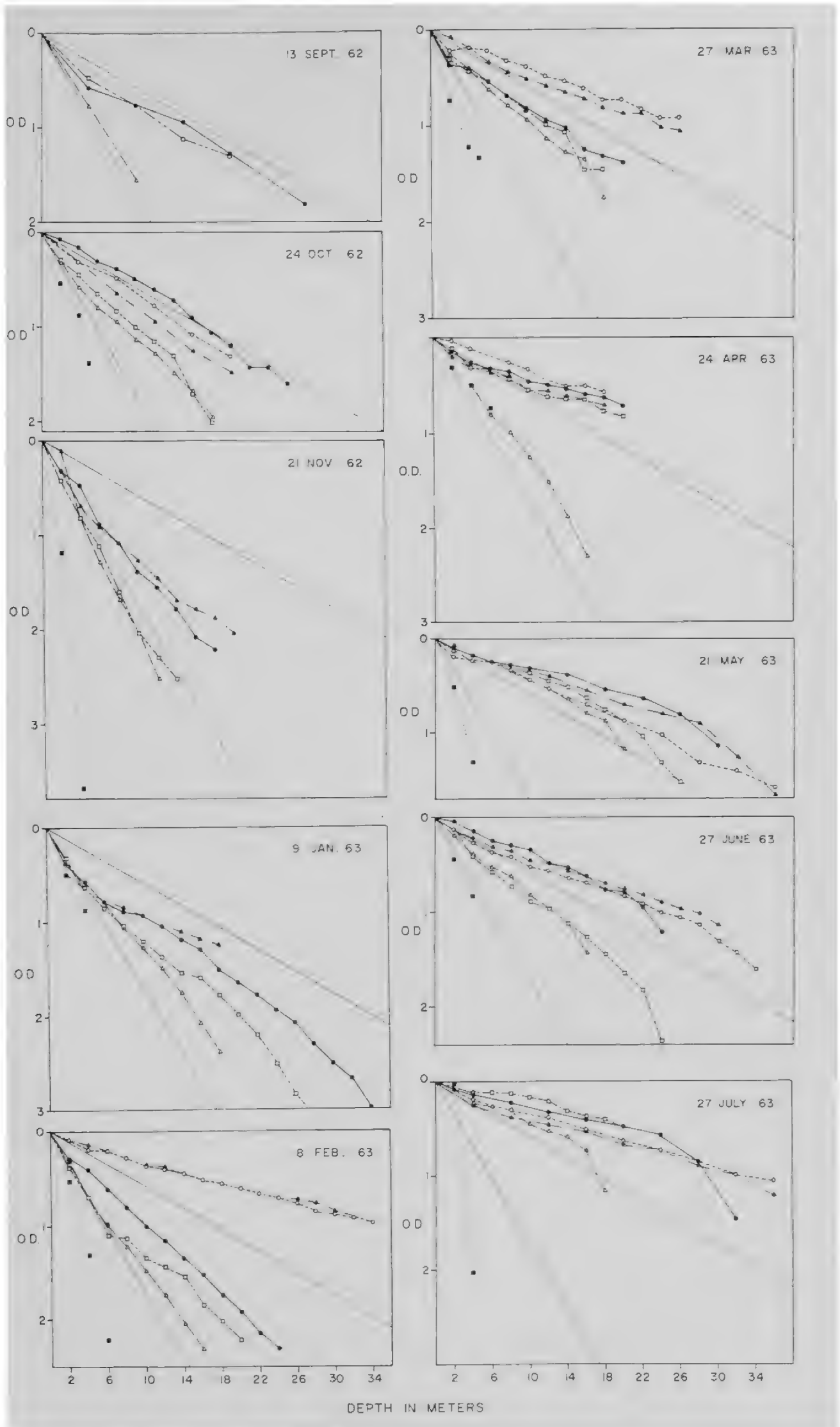


FIG. 4. Water density (sigma t) for the sampling area. Dashed lines indicate density anomalies.

FIG. 5. Optical density vs. depth for Stations 2 through 7. The solid lines at 30 and 60 degree angles are arbitrary divisions for water mass separation.

Station 2
Station 3
Station 4
Station 5
Station 6
Station 7


13 SEPT. 62
24 OCT 62
21 NOV 62
9 JAN. 63
8 FEB. 63
27 MAR 63
24 APR 63
21 MAY 63
27 JUNE 63
27 JULY 63
OD
O.D.
DEPTH IN METERS

Stations 3 through 7, while *Anchoa mitchelli* predominated inshore. *Scomberomorus maculatus* also occurred only in the offshore water mass from May through July 1963 and September 1962 (Table 1). This correlates with the water masses indicated by optical densities in Fig. 5. Proof that these species indeed follow water masses is shown by the collection of larval *Scomberomorus* and *Harengula* at Station 1 in August 1963 when the clear blue water (associated with Stations 3 and 4 in July) moved inshore and surrounded Station 1.

At other seasons the correlation of larval types with water masses did not seem distinct but *Paralichthys* sp., *Poronotus triacanthus,* and *Etrumeus teres* seemed to spawn in Gulf water and *Micropogon undulatus* and *Leiostomus xanthurus* in coastal water. *Brevoortia patronus* spawned in both. Some other species spawned only offshore, but many of these are benthic species which may not be influenced as much by water masses as are pelagic ones.

Distinguishable Water Masses

Two kinds of water, coastal and Gulf, are distinguishable within 25 miles of shore. The divisions in most cases are somewhat arbitrary, but were separable by large differences in light penetration. There was a third intermediate mass, indicated by light penetration, but it may be part of the Gulf mass, since gulf spawning species spawned in it. These three water masses were noted during February, March, and June. In October, November and January, the intermediate water mass was the clearest present. No intermediate water mass was noted in May and July, which were relatively calm months. The intermediate water mass may be a temporary (wind dependent) phenomena, caused by temporary increases in turbidity.

Curl (1959) used salinity differences to separate the coastal and Gulf waters in the Northeastern Gulf of Mexico. However, in his area, rainfall is high enough that a large difference exists between the two types of water. In the Western Gulf of Mexico, rainfall is often slight, as during our study, and coastal waters are sometimes equal or greater in salinity than offshore Gulf waters. Therefore, salinity differences alone could not be used for distinguishing water masses in this study. Temperature relationships, water density, and optical density were used instead.

Gulf water was not encountered within the 25-mile sampling transect during October, November and January. Water temperature (Fig. 2) was about the same from top to bottom increasing with depth during January. Water density (Fig. 4) was practically homogenous during October and November with salinities causing density layering in

Table 1

Distribution of larvae of pelagic fishes by station for collection months

Species	Sept.	Nov.	Feb.	Mar.	May	June	July
Brevoortia patronus	.....	.....	2–7	2,4	.....	.....	.....
Harengula pensacolae	4–7	.....	.....	.....	4–6	3–6	2–7
Etrumeus teres	.....	.....	4–6	6–7	.....	.....	.....
Anchoa hepsetus	4–5	.....	.....	3–4	4–7	2–3	2–3
						5–7	6–7
Anchoa mitchelli	.....	2	2	.....	2	.....	.....
Scomberomorus maculatus	4–7	.....	.....	.....	4–7	3,7	6–7
Sphyraena barracuda	6–7	.....	.....	.....	7	7	7

January. During these three sampling periods, all stations exhibited about the same optical density and extinction was greater per unit of depth than during any other time of the year (Fig. 5).

Although absent during November and January, a distinct gradient of water masses existed along the transect in February. The outer two stations exhibited more horizontal optical density plots, indicating the presence of clear Gulf water. The same conditions prevailed in March.

During September and April, separation of coastal and Gulf water was clearly marked between Stations 3 and 4. The clearest demarcation was shown in the optical density (Fig. 5). The slope of the optical density line was considerably less in the outlying stations as compared to Stations 2 and 3. For both months temperature profiles (Fig. 2) showed thermal stratification at all stations except Station 3 in September and 3 and 4 in April. A tongue of more dense water was present under the outer four stations during April and September (Fig. 4).

During the summer (May, June and July), Gulf water moved toward or away from shore depending on winds and other conditions. At the sampling times for May and July, Gulf water was near shore while in June, associated with strong southeast winds, the Gulf water had moved about 15 miles from shore. Optical density profiles for May and July showed virtually the same water at Stations 3 through 7 with more turbid water at the inshore station (Fig.5). The intermediate mass could be distinguished during June; a fairly turbid mass at Station 2, an intermediate one at Stations 3 and 4, and the clear Gulf water at Stations 5, 6 and 7 (Fig. 5). Temperature profiles exhibited the same sort of pattern. The water was thermally stratified at all Stations during May and July and at Stations 5, 6 and 7 during June (Fig. 2). Sigma t profiles showed various degrees of horizontal layering, indicating a certain amount of stability (Fig. 4). In these coastal waters, plots of the more traditional temperature versus salinity tended to confuse the otherwise "clear" pictures (in terms of optical density) of water mass separation. Obviously, clear water within the range of the transect is present both winter and summer.

Acknowledgments

This study was supported by a grant of funds from the Texas Game and Fish Commission, Contract #4413-578. Dr. H. T. Odum, former Director of the Institute of Marine Science and now at the Puerto Rico Nuclear Center and the University of Puerto Rico, initiated the study and served as principal investigator for the grant. Don Wilson, Ray McKnight, Mrs. Jean Copeland, and William Gillespie helped with the field and laboratory work. William Gillespie drew the figures. Captain Herman Moore was the boat operator on all cruises.

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U.S. Navy. 1952. Tables for sea water density. Publs. U.S. hydrogr. Off. No. 615, 265 pp.

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A Quantitative Study of Selected Nearshore Infauna Between Sabine Pass and Bolivar Point, Texas[1]

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Abstract

Five shallow sublittoral stations between Sabine Pass and Bolivar Point, Texas were sampled seasonally from September, 1962 through September, 1963 to determine the influence of substratum and season on selected infauna. Ten 6-inch cores, ¾ to 2 inches in diameter, were taken at each station during each sampling period. The infauna studied included crustaceans (17 species), polychaetes (12 species), and mollusks (6 species).

Two nonparametric statistical tests were utilized to test the significance of the substratum and season on the species. The species that occurred on sand bottoms did not occur on mud bottoms, with two exceptions. Therefore certain species were designated as diagnostic of sand or mud. The diagnostic species included *Amphithoe* sp., *Corophium cylindricum*, *Haploscoloplos fragilis*, *Haustorius* sp., *Lumbrinereis tenuis*, *Neanthes succinea*, *Paraonis* sp., *Petricola pholadiformis*, *Spio setosa*, and *Streblospio benedicti*. Among the sand dwelling species some exhibited a definite preference of one sand station over another. All of the diagnostic species were found to have some degree of seasonal variation. Hurricane CINDY had very little effect on the organisms living in sand, but had drastic effects on those occupying mud bottoms. The optimum depth below the surface occupied by most species was 1 to 2 inches.

Introduction

Numerous studies have shown that the coastline of the area between Sabine Pass and Bolivar Point, Texas has undergone alteration (LeBlanc and Hodgson, 1959). The most recent major change was associated with Hurricane CARLA in September, 1961 (Hulings, 1961). Some minor changes were recognized after Hurricane CINDY in the fall of 1963. In view of the absence of infaunal data from this area, a quantitative sampling program similar to that of Jones (1961) was initiated.

This study was designed to permit the evaluation of two principal variables on the infauna, shallow water sediments, namely, mud and sand, and season. The interaction of various species, and the net effects produced by various chemical and physical factors on selected infauna were also investigated. A major limitation of this study was the lack of detailed sediment analysis regarding particle size and organic content.

Methods

Sampling was conducted from Bolivar Point to Sabine Pass in the very shallow sublittoral zone. Fig. 1 shows the location of the selected stations. Each station was occupied seasonally over a period of one year beginning September, 1962 through Septem-

[1] Based on part of a thesis submitted by the first author in partial fulfillment of the requirements for the degree of Master of Science at Texas Christian University, Fort Worth.

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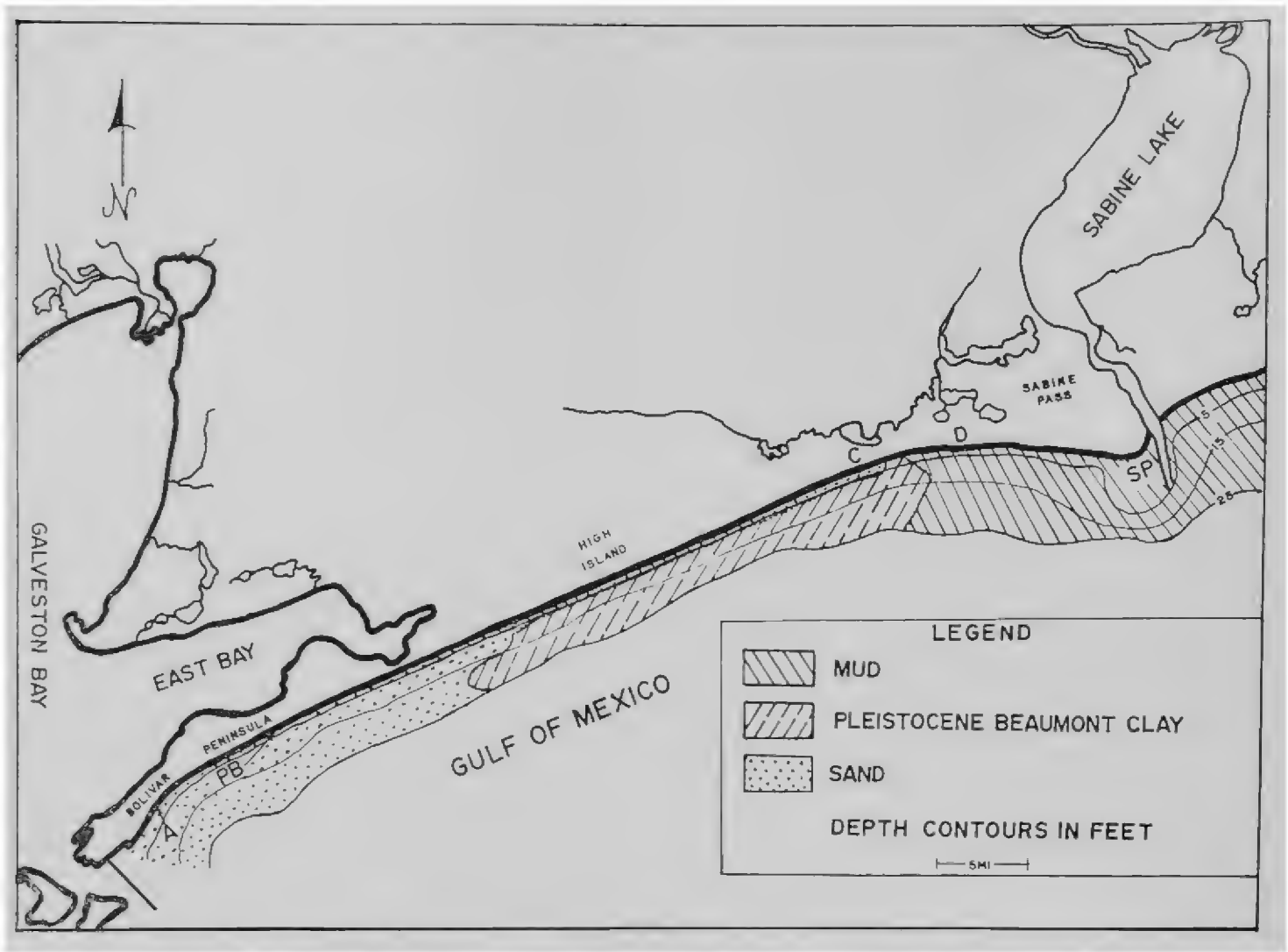

FIG. 1. Location of stations and distribution of sediments (after Feray, unpubl.).

ber, 1963. Five stations were selected on the bases of bottom sediment, salinity range, and turbidity. The bottom types can be divided into two large categories: sand and mud.

Station A—Bolivar Point, sandy bottom
Station PB—Pearl Beach, sandy bottom
Station C—McFadden Beach, sandy bottom
Station D—McFadden Beach, muddy bottom
Station SP—Sabine Pass, muddy bottom

At Stations A, PB, and C the substrates were similar; there was, however, variation in other environmental factors such as salinity, particle size and wave action. Stations D and SP were both mud bottoms and the same environmental factors could be evaluated in relation to this type of habitat.

Ten 6-inch cores, 2 inches in diameter, were taken at four of the stations below low tide in about four feet of water during each sampling period and preserved in neutralized 10% formalin. A fifth station, Pearl Beach, was sampled to determine the influence of wave action upon the organisms. It was necessary to sample this station with a ¾-inch core because of the coarseness of the substratum.

During each sampling period an additional sample was taken to determine the sediment temperature at various depths. The same core was sectioned at one inch intervals to determine the depth of penetration of certain organisms. Duplicate water samples at the sediment-water interface were taken each time for oxygen and salinity determination. Qualitative sampling was employed at each station during the fall of 1962 for faunal comparison with the core samples.

Two nonparametric statistical designs were employed in this study. The Mann-Whitney U Test was employed to test the effect of habitats on certain organisms during each season and the overall significance for the year. The Kruskal-Wallis one-way analysis of variance by ranks was employed to test the significance of seasons upon the species. The level of significance for rejection of the null hypothesis was ($D<0.05$).

To determine the effect of seasons for the diagnostic species, the station with the greatest number of individuals was used. It was felt that the significance of seasonal variation would be more evident with a larger number of organisms.

Results

The total number of individuals of each species for ten samples taken at each station during the five sampling periods is shown in Table 1. A total of 1824 specimens representing 35 species of polychaetes, crustaceans and mollusks, the only groups studied, were recorded during the study. The most abundant group, in terms of number of species, was the crustaceans with 17, followed by the polychaetes with 12 species and the mollusks with 6 species. In terms of numbers of individuals, the polychaetes were the most abundant with 1030 specimens, followed by the crustaceans with 506 specimens and the mollusks with 288 specimens. Other groups are, of course, important components of the infauna but these groups were not studied.

Table 2 summarizes the hydrographic data for each station. The salinity was generally higher at Stations A and PB than at the other stations during the study. The oxygen and temperature conditions between stations did not vary nearly as much as the salinity.

Discussion

This study was designed to evaluate the effect of two variables on selected infauna, season and substratum. Season affects the organism through changes in temperature, tides, salinity and oxygen concentration.

The nature of the substratum is another important ecological factor controlling the distribution and types of organisms present. It was found, with two exceptions, that the organisms occurring on sand bottoms did not occur on mud bottoms. For this reason, the sand and mud stations were treated separately as the effect was obvious without statistical treatment.

Ecology of Diagnostic Species

Paraonis sp.—During the winter and fall, no significant difference was found in the number of individuals of *Paraonis* sp. at Stations A and C. During the spring and summer, however, a significant difference between the two stations was found, Station A ($P<0.02$) being preferred over Station C ($P<0.002$).

It was determined with reasonable significance that there was an overall preference of Station A over Station C by *Paraonis* sp. ($P<0.041$). Results for Station A showed that this species was much more abundant during the spring and summer than during the fall and winter. Seasonal variation was significant at the 0.01 level of confidence. The principal difference between Stations A and C was that the latter was more turbulent. Evidence suggests that *Paraonis* sp. prefers warm, quiet water over cooler, more turbu-

TABLE 1

Total number of individuals of each species at all stations for each sampling period

Species	Station A F 62	W 63	Sp 63	Su 63	F 63	Station PB F 62	Sp 63	Su 63	F 63	Station C F 62	W 63	Sp 63	Su 63	F 63	Station D F 62	W 63	Sp 63	Su 63	F 63	Station SP F 62	W 63	Sp 63	Su 63	F 63
Polychaeta																								
Cirriformia filigera																						2		
Diopatra cuprea																						2		
Haploscoloplos fragilis	25	104	31	49	30							1		2										
Lumbrinereis tenuis	2	3	3	4	2		2			5	3	23	1	5	2	16	2	11	1				1	
Magelona papillicornis	1		2				2	1				3	5											
Neanthes succinea																4	28	4		4	50	44	14	4
Nepthys picta	1		1					1																
Paranois sp.	21	24	24	62	34			1		4	15	1	6	21										
Polydora ciliata																3		5		1	1	3	8	
Spio setosa	1				2		1			41	3	5	32	10										
Spiophanes bombyx	2		2	1			1	1				1	3											
Streblospio benedicti	2			147	40																			
Crustacea																								
Actinocythereis subquadrata				1																				
Acuticythereis tuberculata	1																							
Acuticythereis sp.				2																				
Amphithoe sp.															137			1				9	8	
Anomalocera patersoni					2						1	5	10	9										
Corophium cylindricum																3	1					63	2	
Cytherura johnsoni				8																				
Cytherura sp.				1																				
Daistylis polila			1																					
Haustorius sp.	8	11	30	1		2	12	11		18	19	24	53	12										
Lepidopa benedicti								2					1											
Mysis stenolepis				2	2	1			3			2	1	2										
Neopanope texana																		2					1	2
Paracypris sp.			1				1					2												
Unidentified amphipod							4																	
Unidentified cumacean			2									2	1											
Unidentified isopod						1		1				3		1										
Mollusca																								
Anachis obesa																	1	1					3	
Donax variabilis	1				5			3	2				2											
Mulinia lateralis				1																			2	
Natica pusilla			1									1												
Petricola pholadiformis																2	1	184	13	1	1	18	34	
Tellina sp.			11																					

TABLE 2

Summary of hydrographic data for Stations A, PB, C, D, and SP

	Fall 62			Winter 63			Spring 63			Summer 63			Fall 63		
Sta.	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l	T C	S ppt	O_2 ml/l
A	33.0	32.0	5.0	10.0	27.7	7.3	29.5	34.4	5.0	30.0	34.8	4.6	27.3	29.6	4.9
PB	32.0	29.9	4.7	...	28.0	..	28.0	34.3	5.1	32.1	35.0	4.4	27.5	27.2	4.9
C	33.0	24.7	4.7	9.0	25.3	7.2	27.1	33.5	5.3	33.1	34.4	4.4	27.4	22.1	5.1
D	33.0	24.3	4.8	8.5	25.4	7.2	27.0	33.1	5.2	33.2	34.4	4.3	30.1	22.0	5.8
SP	31.0	24.2	4.5	6.5	28.7	7.3	29.5	28.8	6.4	32.0	34.0	6.9	.....	6.9	2.7

lent water. One might speculate further to say that turbulence or sediment size plays a greater role in the ecology of the organism than environmental fluctuations resulting from seasonal changes because there is a greater difference in the number of organisms between stations than between seasons. According to Jones (personal communication) the genus *Paraonis* has not been reported from the Gulf of Mexico.

Streblospio benedicti—This species was found only at Station A and, therefore, was not treated statistically. *S. benedicti* occurred in extremely large numbers during summer and fall, but none were recovered from samples during the colder months. It appears that temperature may be a very important limiting factor to this species.

Haploscoloplos fragilis—*H. fragilis* was found in abundance throughout the year at Station A, but only three specimens were found at Station C. The preference of Station A over Station C, therefore, was highly significant ($P<0.014$). This species was much more abundant during the colder months ($P<0.001$).

It appears that temperature influences *H. fragilis* directly, the peak of abundance occurring during the winter. Another possibility is that the increase during the winter results primarily from the lack of competition from other species.

Haustorious sp.—This small amphipod appeared to be fairly abundant at Stations A and C. Statistical tests showed no significant difference between the stations during winter and spring. During fall, the difference became significant ($P<0.05$) and by summer it was highly significant ($P<0.002$).

Spio setosa—During the winter and spring there was no significant difference in the abundance of *S. setosa* at Stations A and C. During the summer and fall, however, the difference between stations was highly significant ($P<0.002$). An overall test of significance showed that Station C was preferred, in general, to station A ($P<0.041$). Seasonal variation was significant at the 0.001 level of confidence at Station C. Seasonal difference probably accounts for the lack of significance between the two stations during winter and spring.

These data suggest that there is some ecological factor present during the warmer months at Station A which is not apparent at Station C during any of the seasons. It seems plausible, therefore, to attribute the highly significant difference between the two stations in the summer to some competitive species. The competition would be one which occurs only at Station A and is only abundant during the summer. The only species recovered in the samples which fits this description is *Streblospio benedicti.*

Neanthes succinea—This polychaete was found at Stations SP and D. There was no significant difference in the number of specimens found at these stations except during the winter ($P < 0.002$). Station SP differs from the other mud stations in several ways including a greater salinity range, a greater amount of organic detritus in the mud, and less turbidity. *Neanthes succinea* was significantly affected by seasons ($P < 0.001$), being most abundant at Sabine Pass during the warmer months. *Neanthes succinea* was also found to be extremely euryhaline, occurring at salinities ranging from 6.9 ppt at Sabine Pass after a flood caused by Hurricane CINDY to 34.4 ppt during the summer at Station D.

Petricola pholadiformis—Statistical treatment showed this species had no preference of one station over theo ther except during spring. The seasons, however, did show an effect on the population number ($P < 0.01$). *Petricola pholadiformis* was more abundant during spring and summer than during the fall and winter. Most of the observed individuals of this species were juvenile, but several adult specimens were recovered.

Corophium cylindricum—Only small numbers of this species were obtained from Station D and very few from SP except during the spring. The data suggest that there are great seasonal influences at Station SP. The abrupt increases in number during the spring also effect a significance between stations during this season.

Amphithoe sp.—This organism was found in great numbers during the fall of 1962 at Station D. Small numbers were found during the spring and summer at Station SP. There were no other specimens found except for one during the summer at Station D. As suspected, statistical treatment shows a high degree of significance for seasonal influence ($P < 0.002$). The same variable which caused a seasonal influence also caused a significant difference between stations during the fall ($P < 0.002$). Overall, however, *Amphithoe* sp. showed no preference as to stations.

The fact that this species was not found at Station D in any abundance after the fall of 1962 may be due to the gradual deposition of sand over the mud.

Lumbrinereis tenuis—This species was found at all four stations. A comparison of Stations C and D indicated there was no preference of sand or mud by the organism. Seasonal influence was shown to be significant at the .01 level of confidence.

Effect of Hurricane *CINDY* on the Diagnostic Species

During the fall of 1963, Hurricane CINDY struck the Texas Gulf Coast. Samples were taken after the hurricane so that a comparison with the previous fall could be made to determine if any significant changes in the diagnostic species occurred. Several investigators have reported mass mortalities resulting from hurricanes (Brongeersma-Sanders, 1957; Wells, 1959; Thomas et al., 1961; Stoddart, 1962; Tabb and Jones, 1962). Most agree that several factors such as stranding, reduced salinity, oxygen depletion caused by decomposition, suffocation, either independently or collectively, cause mass mortality. Goodbody (1961) has documented mass mortality resulting from prolonged reduction of salinity caused by flooding.

Hurricane CINDY had a drastic effect on the organisms occupying the muddy substratum at Stations D and SP. The effect of those in a sand environment, however, was not as obvious. The only organisms which survived the storm at Sabine Pass were *Nean-*

thes succinea, and a small crab, *Neopanope texana.* To withstand the effects of the hurricane at this station, the organisms must be extremely euryhaline. The salinity at Station SP dropped to 6.9 ppt following the hurricane from 34.0 ppt at the previous sampling period.

The oxygen concentration was depleted as a consequence of organic matter and hydrogen sulfide being churned up from the mud bottom as a result of the hurricane.

There were no organisms recovered from the samples at Station D following the hurricane except for one specimen of *Lumbrinereis tenuis.* Many factors may have contributed to the death of the organisms at this station. Turbulence and suffocation due to mud were probably responsible for some deaths. Some organisms may have been stranded by high tides while others were buried.

Effect of Wave Action

A station was selected to determine the influence of wave action on the organisms. Station PB, Pearl Beach, sufficed for this purpose. Organisms are influenced not only by the turbulence of the wave action, but also by the accompanying modification of the substratum. As a general rule, the greater the turbulence, the larger the particles composing the substratum, as small particles will remain in suspension to be carried away.

The only polychaete found at both Stations A and C, but not at PB was *Haploscoloplos fragilis.* This species was found in greatest abundance at Station A, which was subjected to very little wave action. Small crustaceans also appeared to prefer the less turbulent environment. Six species of ostracods were found at Station A; whereas, only one species was found at Station PB.

Depth of Penetration

Most of the species appeared to stay at approximately the same depth throughout the year, the optimum usually being from 1 to 2 inches as seen in Table 3. The maximum depth of penetration also appeared to be relatively constant through the year with the exception of *Neanthes succinea,* which was recovered from a depth of 7 inches during the spring, the maximum being 2 inches in the winter. The temperature decrease from the

Table 3

Maximum and optimum depth of penetration (in.) of selected species

	Total No. Specimens	Maximum Depth	Optimum Depth
Polychaeta			
Haploscoloplos fragilis	21	3	1
Lumbrinereis tenuis	6	2	1
Neanthes succinea	15	7	1
Paraonis sp.	24	5	2
Polydora ciliata	3	1	1
Spio setosa	9	3	2
Streblospio benedicti	20	2	1
Crustacea			
Amphithoe sp.	31	4	1
Corophium cylindricum	5	1	1
Haustorius sp.	25	4	2
Mollusca			
Donax variabilis	7	1	1
Petricola pholadiformis (Juvenile)	20	1	1

sediment-water interface to a depth of six to eight inches was, on the average, 1 to 2 C at all stations during all seasons.

Conclusions

This study provides a baseline for future reference regarding changes in the infauna of the area between Sabine Pass and Bolivar Point. The entire area is unstable in terms of sediment movement and deposition and it follows that much of the infauna of the area will change assuming a close correlation between infauna and sediment. Certain broad environmental limits have been established for selected components of the infauna.

An indication of the effect of hurricanes on the infauna of the area has, likewise, been demonstrated. Additional investigations along this line are needed since the Texas Coast is frequently subjected, either directly or indirectly, to hurricanes. There is little doubt that mass mortality due to hurricanes is significant on the Texas Coast.

Acknowledgments

The assistance of the Faculty Research Committee of Texas Christian University who provided a grant for the tenure of this study is greatly appreciated. It is also a pleasure to acknowledge the assistance of Dr. Meredith Jones of the U.S. National Museum for identification of certain polychaetes and of Mr. Bill Blieden of Beaumont, Texas.

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Addendum

It recently came to the author's attention that the *Haustorius* sp. given in this paper belongs to the genus *Acanthohaustorius* which has not previously been reported from the Gulf Coast. It appears that two new species are involved. We are indebted to Dr. E. L. Bousfield of the National Museum of Canada for this information. The *Amphithoe* sp. referred to in the text belongs to the genus *Microprotopus*. The specimens are neither of the two known species, *M. maculatus or M. longimanus,* and is, therefore, a new species. We are indebted to Dr. J. L. Barnard of the Smithsonian Institution for this information.

Distribution and Growth of Penaeid Shrimp in Mobile Bay, Alabama[1]

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Abstract

The distribution and growth of penaeid shrimp were studied in Mobile Bay, Alabama, by means of monthly trawl and seine samples at 24 stations from 1953 to 1955.

Young brown shrimp appeared from late March or April to November, and were concentrated in water 2 to 3 feet deep among attached vegetation. In winter they grew 13 to 18 mm per month; in spring and summer 30 to 35 mm per month, with growth as much as 50 mm per month in the very young.

Young white shrimp appeared from June to September, and were concentrated in water less than 2 feet deep in areas with large amounts of organic detritus. In winter they grew 14 to 27 mm per month; in summer 18 to 30 mm per month, with growth as high as 65 mm per month in the very young.

Post-juvenile shrimp of both species (75–80 mm) moved to the deeper parts of Mobile Bay and then to the Gulf of Mexico. White shrimp abundance in the deeper parts of the bay involved two peaks: one in late July and August; the other in October and November. Brown shrimp were most abundant in the bay in June, July and August.

Introduction

At the request of the Seafoods Division of the Alabama Department of Conservation, a survey of shrimp in Mobile Bay was carried on from July 1953 to September 1955 to provide data that could be used for managing stocks of shrimp in state waters. Observations were made to determine (1) the seasons in which postlarval and juvenile shrimp are present in the bays, (2) their approximate growth rates while in the bays, (3) their general movements within the bays, (4) their size distributions in different water depths, salinities, and areas, and (5) the fishing pressure. Findings on the first three points are presented herein.

Fishery statistics show the 1948 catch of white shrimp in Alabama to have been two-thirds of the 1945 catch. (No statistics are available for the intervening years.) As the availability of white shrimp gradually declined, the brown shrimp were fished more extensively, and by 1959 comprised 61% of the total Gulf catch (Power, 1961).

Postlarval white shrimp, *Penaeus fluviatilis* Say,[1] first appear in the bays at about 18 mm in length (Gunter, 1950). By aquarium studies, Johnson and Fielding (1956) found that white shrimp attain a size of 14 mm 21 days after hatching; a 39-mm size is attained in 28 days. This would indicate that shrimp are less than a month old when they first appear in the bays. Two separate recruitment peaks were noted in Texas by Gunter (1950) and in North Carolina by Williams (1955). Ingle (1956) found continuous re-

[1] Based on a part of a dissertation presented to the faculty of the Agricultural and Mechanical College of Texas in partial fulfillment of the requirements of the Ph.D. degree under the guidance of Dr. S. H Hopkins.

[1] Gunter (1962) presents evidence that the proper name of the Atlantic North American white shrimp is *Penaeus fluviatilis* Say. Holthius (1962) advocates the retention of *P. setiferus* (L).

cruitment without peaks in bays of the northern Gulf region of Florida. Growth of these young white shrimp has been estimated to be over 30 mm per month (Gunter, 1950; Williams, 1955; Loesch, 1957).

Gunter (1950) found young brown shrimp, *P. aztecus* Ives, in Texas bays throughout the year, but less frequently in winter. He found apparent peaks of recruitment in early summer and in fall. Ingle (1956) reported that young brown shrimp first entered Apalachicola Bay, Florida, in April. Loesch (1957) found large recruitments of brown shrimp through November in the rivers north of Mobile Bay. The only estimate of growth rate of young brown shrimp was made by Williams (1955) who said it exceeds 40 mm per month.

Pink shrimp, *P. duorarum* Burkenroad, are found only sporadically in the northern Gulf. Darnell and Williams (1956) reported range extension to Lake Pontchartrain, Louisiana. Ingle (1956) found too few pink shrimp in Apalachicola Bay, Florida, to attempt determinations of growth or movement. Nevertheless, this shrimp is of some commercial importance in Mississippi and Texas.

Mobile Bay

Mobile Bay (Fig. 1) with an overall area of 297 square nautical miles, averages 9.8 feet in depth at mean low water, and attains a maximum depth of 60 feet off Fort Morgan near the juncture of the bay with the Gulf of Mexico. The Mobile and Tenesaw Rivers enter at the north. To the south the bay has two major outlets: the main pass which empties directly into the Gulf of Mexico and Pass aux Herons which empties into Mississippi Sound at the southwest corner of the bay. The bottom is essentially flat except for a dredged 35-foot ship channel running the length of the bay slightly west of mid-line, and the associated spoil area mostly to the west of the channel.

Circulation

Austin (1954) studied the circulation in Mobile Bay and found that during the incoming tide, water enters the bay through the main pass. It is deflected to the right (east) of the entrance and then gradually swings back to the left as water from Bon Secour River and Bay serves as a buffer to the jet-like entrainment, shunting the flow towards the north and setting up eddies. At the northern end of the bay, river flow from the Alabama and Tenesaw Rivers is deflected to the western side of the bay and continues to move down the bay toward the Gulf even during flood tide. At the beginning of flood in the main pass, water is still ebbing through Pass aux Herons and continues to ebb for 15 minutes to an hour before it, too, begins to flood in a northeasterly direction. This water joins the entrainment from the main pass and moves toward the eastern side of the bay.

At ebb tide, the water in the entire bay moves predominantly south in a pattern much simpler than that at flood tide. Overall, there is a general counterclockwise circulation in Mobile Bay which has superimposed upon it convergences and divergences that indicate a complex vertical local circulation.

Descriptions of Stations

Shrimp at twelve stations in Mobile Bay were sampled monthly with a shrimp (otter) trawl. Samples were also collected once a month by seining at twelve shore stations in Mobile Bay and one in Weeks Bay (Fig. 1).

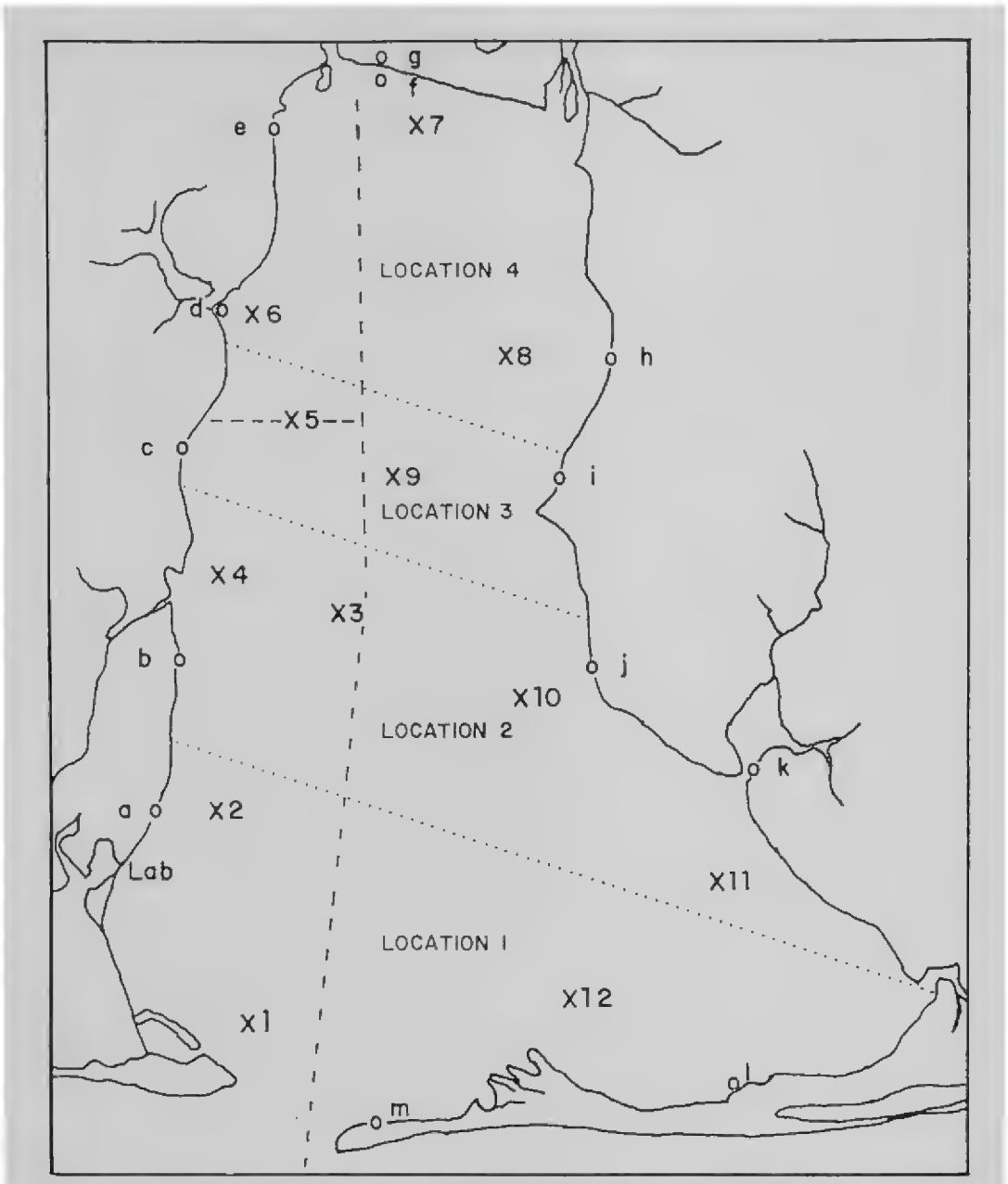

FIG. 1. Locations of stations in Mobile Bay. Bay Stations: X1 Beacon No. 4, X2 Alabama Port, X3 Beacon No. 18, X4 Fowl River, X5 Deer River, X6 Dog River, X7 Devils Channel, X8 Daphne, X9 Dredge, X10 Mullet Point, X11 Bon Secour, X12 Little Point Clear. Inshore and Nearshore Stations: a Alabama Port, b Austins, c Bellefontaine, d Dog River, e Brookley Field, f South of Causeway, g North of Causeway, h Daphne, i Fairhope, j Mullet Point, k Weeks Bay, l Pleasure Point, m Fort Morgan.

Bay Stations. Unless otherwise noted, water depth at the bay stations was about 11 ± 2 feet. Shrimp were frequently fished commercially at Station X1, west of Beacon No. 4 in the Mobile Bay ship channel. Water there was about 18 feet deep. Station X2, off Alabama Port on a mud spot north of Kings Bayou Reef, was also a favored commercial shrimping spot. Station X3 was located in the Mobile Bay ship channel (depth of 35 feet at the time of sampling) at Beacon No. 18. Station X4 was located on mud bottom at the Fowl River Beacon. Station X5 was near Deer River in the Ammunition Dump channel (U.S. Army New Orleans Port of Embarkation) between Beacons No. 9 and No. 13 in 32-foot water. Station X6 was at the Dog River Beacon. Station X7 was located in Devils Channel, a natural, undredged channel in an area of mud flats. Station X8, just offshore from Daphne, was the station nearest shore. Station X9 varied in location but was always near a shell dredge (Bay Towing and Dredging Company) which operated on submerged oyster reefs in the northeastern quadrant of the bay. Station X10 was on a sand and mud bottom near Mullet Point Beacon. Station X11 was located in Bon Secour Bay

just to the southwest of the opening of Weeks Bay. Station X12 was at Little Point Clear, a bend in the Intracoastal Canal near Beacon No. 248.

Inshore and Nearshore Stations. Inshore stations were established at points accessible by automobile. Stations are designated by letter, starting at the southern end of the western side of the bay and moving clockwise around the bay. Nearshore stations were established directly offshore from inshore stations.

Stations a through e were on the western side of Mobile Bay. This side has an actively eroding beach bluff varying in height from 4 feet at Station a to 20 feet at Station e. All had sandy-mud bottom. *Vallisneria americana* Michx. was growing at Stations d and e, and the bottoms there were slightly muddier. Stations f and g were along the causeway which artificially delineates the northern end of Mobile Bay. These stations were not included in the nearshore sampling because they were not accessible by motorboat.

Stations h through m were along the eastern side of Mobile Bay. The old and fully vegetated bluff on the northern portion of this side varied in height from 60 feet at Station h to 2 feet at Station j. *Ruppia maritima* L. was growing at Station j. Station k, in Weeks Bay, was not accessible by motorboat for the nearshore sampling. Station l had an actively eroding bluff. The bottoms on this side of the bay were, with the exception of Station k, far less muddy than those on the western side.

Shrimp Sampling Methods

The commercial otter trawl used in sampling bay stations had a 22-foot 1-inch cork line and a 25-foot 3-inch lead line, with wings and tail of 1¼-inch stretch webbing, ⅝-inch bar. A standard drag consisted of a 30-minute tow at approximately 3 knots. One tow, therefore, swept a bottom area not exceeding 200,000 square feet.

At inshore stations a 20-foot minnow seine was hauled manually in water 0 to 2 feet deep for approximately five minutes, sampling an area about 150 × 20 feet. This was done at each of the inshore stations for the first ten months of the study, when it was decided to use a motorboat to standardize the operation.

A drag-bar net, designed to be operated from a motorboat, was constructed of nylon mesh attached to a heavy bar 30 inches long (Fig. 2). It was dragged from small boats at 2 knots. A drag was begun in about 2 feet of water and continued straight out from the shoreline for 3 minutes. The next drag started at the point the first drag ended and it, too, continued for 3 minutes. Each drag, therefore, sampled progressively deeper water. Three or four such drags were usually made at each nearshore station. The last drag covered an area that included the outer sand bar and terminated in 11-foot water. Then another 3-minute drag was made approximately one mile offshore from the last sand bar.

It soon became obvious that the results obtained from the area sampled by the drag bar (water over 2 feet deep) were grossly different from those obtained by the minnow seine which operated in water less than 2 feet deep. Both techniques were then used for the final five months of the survey.

Temperature and Salinity

Water temperatures of the bay stations, graphed in Figs. 3a and 3b, varied from approximately 10 C in January (as low as 8.5 C) to about 31 C in August (as high as

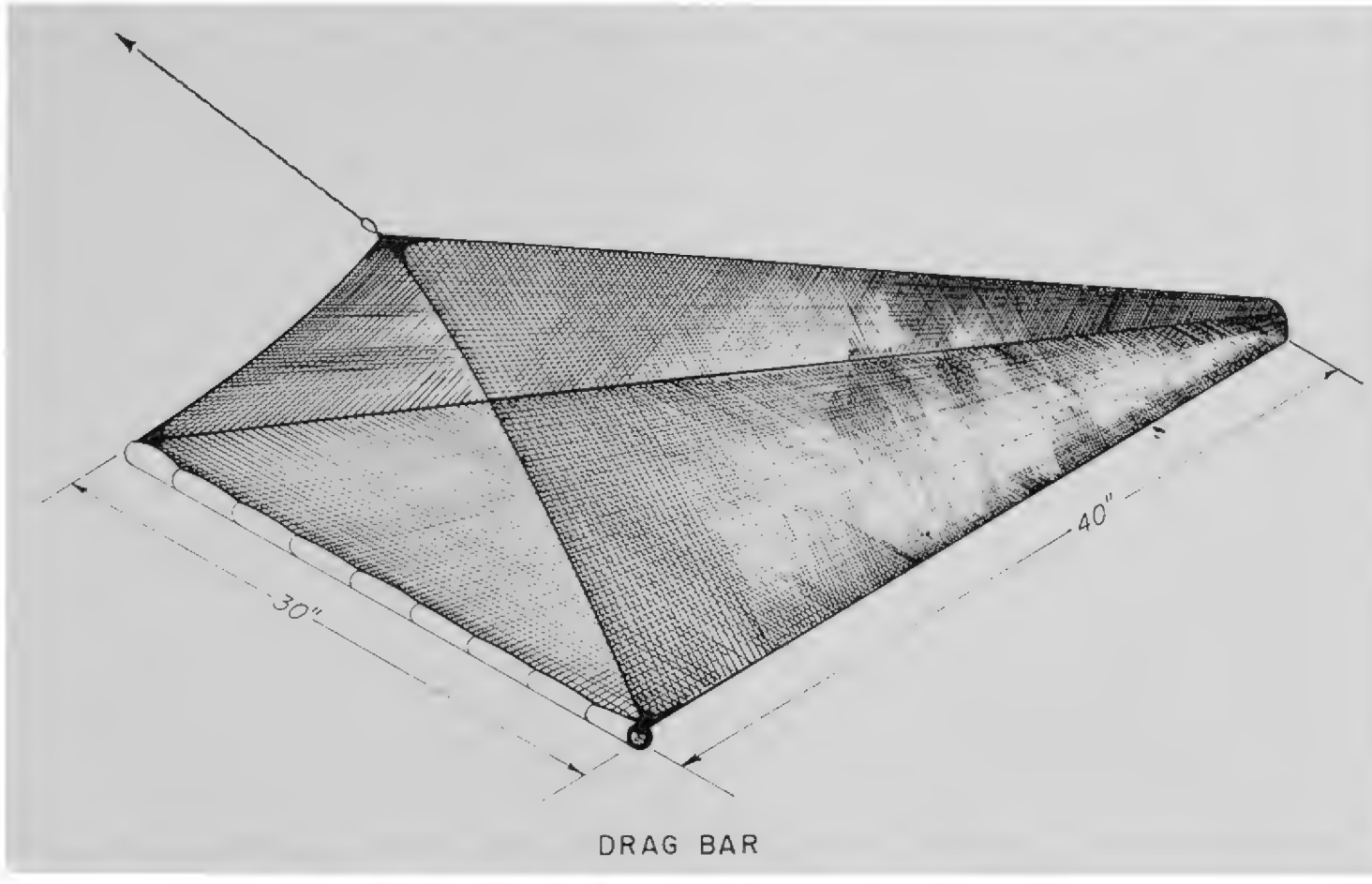

FIG. 2. Drag bar trawl used at nearshore stations.

32 C). Temperatures of shallow water at inshore stations were similar to temperatures at bay stations except that the ranges (9.5 C to 34 C) were a little wider (Tables 2 and 3, Loesch 1962).

Bottom water samples were taken in the bay, and surface water samples were taken at shore stations for salinity determinations with the sliver nitrate method. The salinities for the bay are shown in Figs. 4a and 4b. Generally, salinities were low from January to May and then increased until November when the highest values were recorded. Stations X3 and X5, both in the 30-foot deep ship channels, showed erratic salinity fluctuations. Stratification was common in these locations.

Nearshore salinities varied (Table 6, Loesch 1962) with water at the point farthest offshore being usually more saline than that at the most shoreward location, especially at stations in the lower end of the western side of the bay.

DISTRIBUTION OF YOUNG SHRIMP

Brown Shrimp

In 1955 young brown shrimp first appeared at stations in Mobile Bay on March 24; they ranged from 15 to 24 mm in length. In 1954 the first young shrimp appeared in early April. During both years the largest number of young shrimp were found in May (Fig. 5). Presence of brown shrimp was continuous until November, when shrimp as small as 20 mm were still found. Only one shrimp was found in the near-shore area during December, January, and February, in 1953, 1954, and 1955.

Both drag-bar net and minnow seine samples revealed that more brown shrimp were on the western side of the bay than on the eastern side (Fig. 7), with the exception of station j. Station j which had attached submerged vegetation, produced an average of 33.8 shrimp per 3-minute drag nearest shore (2 to 3-foot water), but all other stations

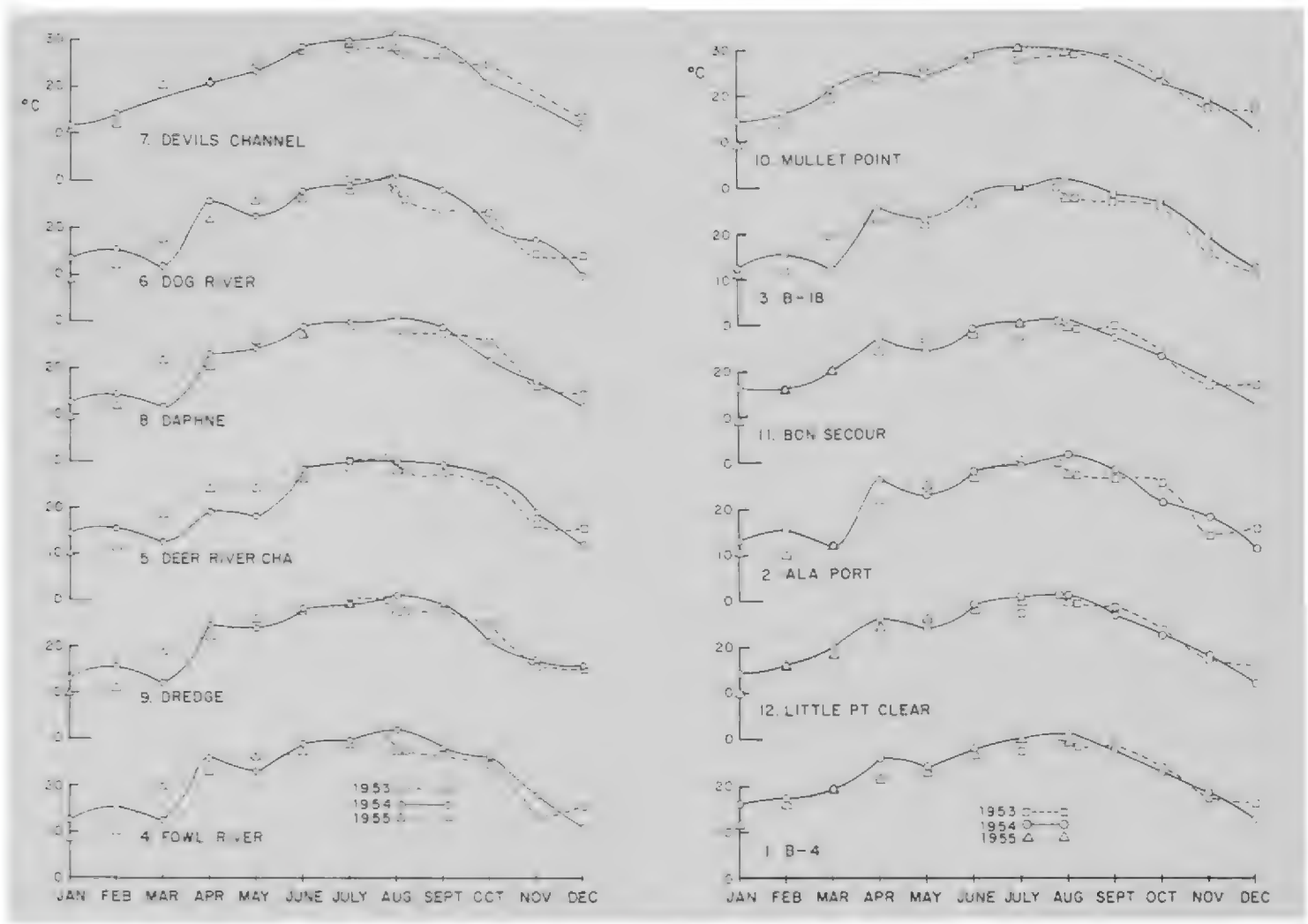

FIG. 3. Bottom salinities at each bay station.

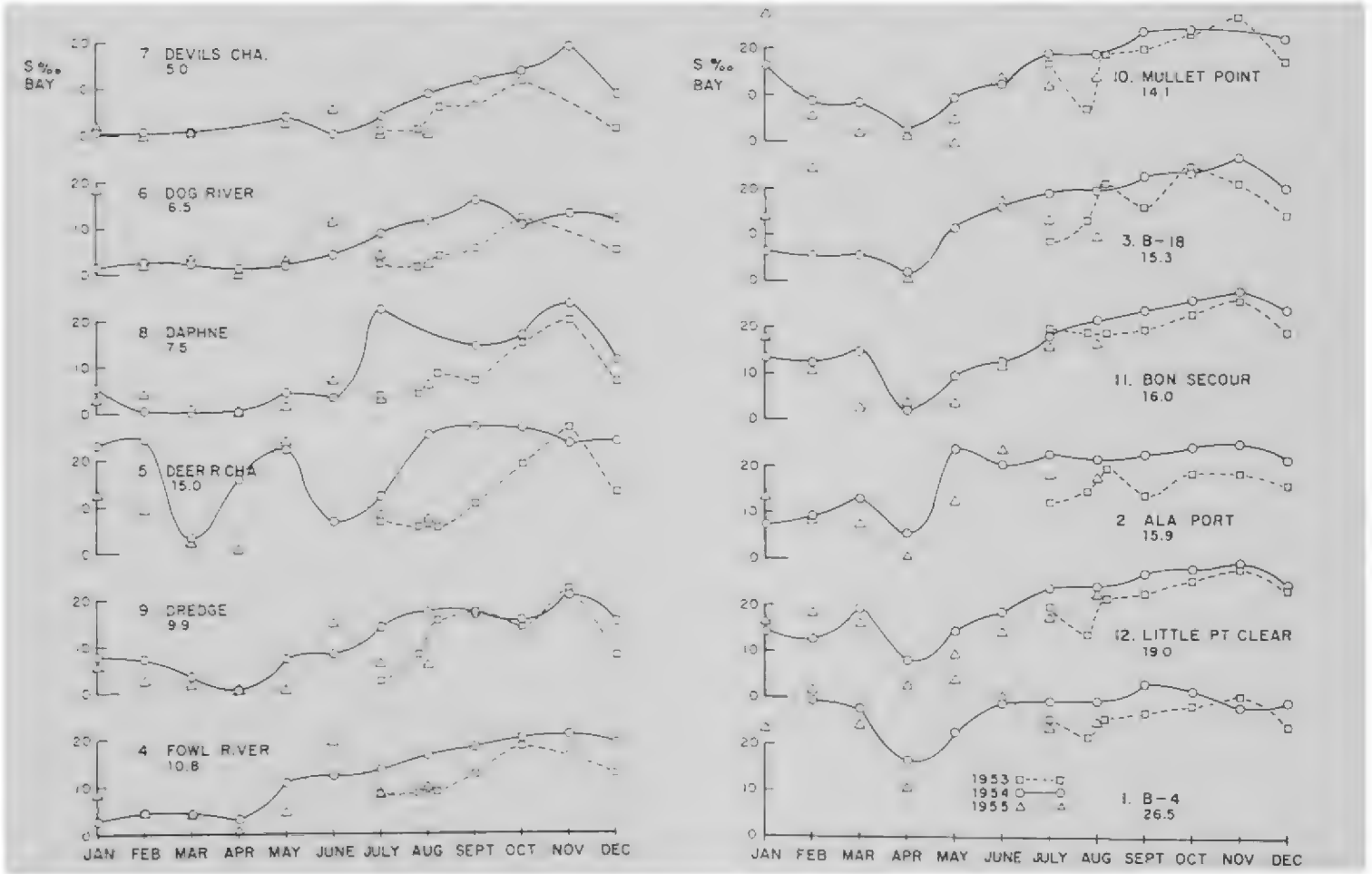

FIG. 4. Bottom temperatures at each bay station.

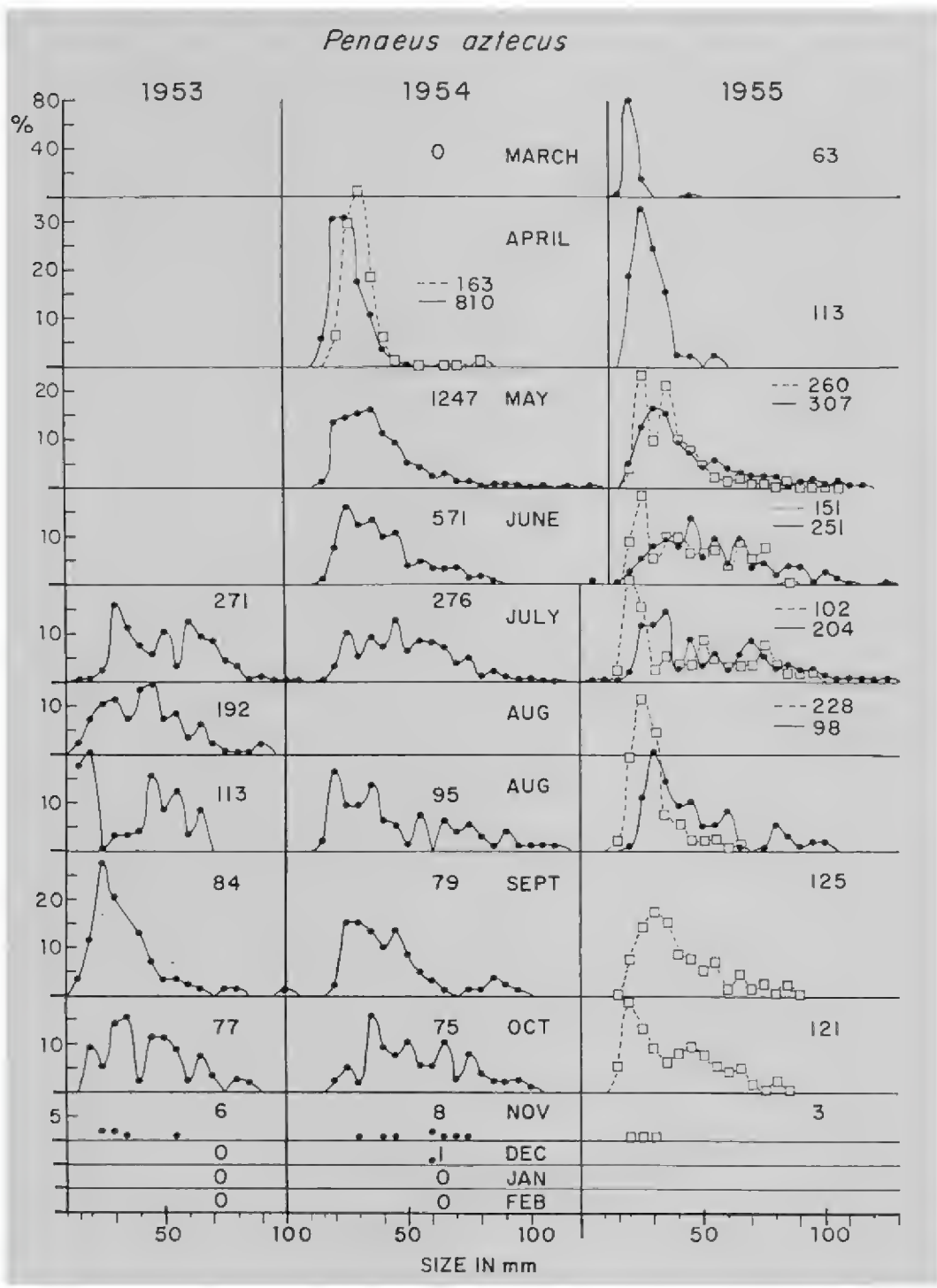

FIG. 5. Length-frequency diagrams by months of all brown shrimp taken in nearshore and inshore areas. Dashed line indicates inshore samples, solid line indicates nearshore samples. Numerals are sample sizes.

on the eastern side produced an average of 0.2 to 3.2 shrimp for each similar drag (Table 9, Loesch, 1962). The five western shore stations produced averages ranging from 14.0 to 18.1 shrimp. At all stations brown shrimp were most abundant in water less than 4 feet in depth and decreased progressively in abundance in deeper waters.

The drag-bar net covered a strip 2½ feet wide. Thus, samples at the ten nearshore stations covered 25 feet of total shoreline. The total shoreline of Mobile Bay is about 425,000 feet long; the gear sampled about 1/17,000 of the shoreline. Assuming that the sampled areas are representative, millions (billions during the peak seasons) of very small young brown shrimp are present in the periphery of the bay from April to September.

White Shrimp

Small white shrimp, first found in the bay in June, increased in abundance until late August or early September. From late November to May no young white shrimp were found in the bay (Fig. 6).

Minnow seine sampling of white shrimp in less than 2 feet of water yielded 1,241 white shrimp from July to September 1955; concurrently only 160 were taken by the drag in the nearshore area in water more than 2 feet deep (Table 8, Loesch 1962). There was no evidence of a relation between depth and abundance in water over 2 feet but less than 11 feet deep (Fig. 7). A description of a concentration of white shrimp at the very edge of the water is given in the following note made on September 11, 1953, at the shore of Station k in Weeks Bay:

> Thousands of whites in a band no more than 6 ft. wide along edge from 0–12″ deep. Very few shrimp in 2½ ft. water approx. 20 ft. out. A few large browns and some seed shrimp (Palaemonetes) in grass about 15 ft. out. Shrimp particularly thick in shade of board put in sand to hold beach—up to 12″ deep. Shrimp visible all through water on edge.

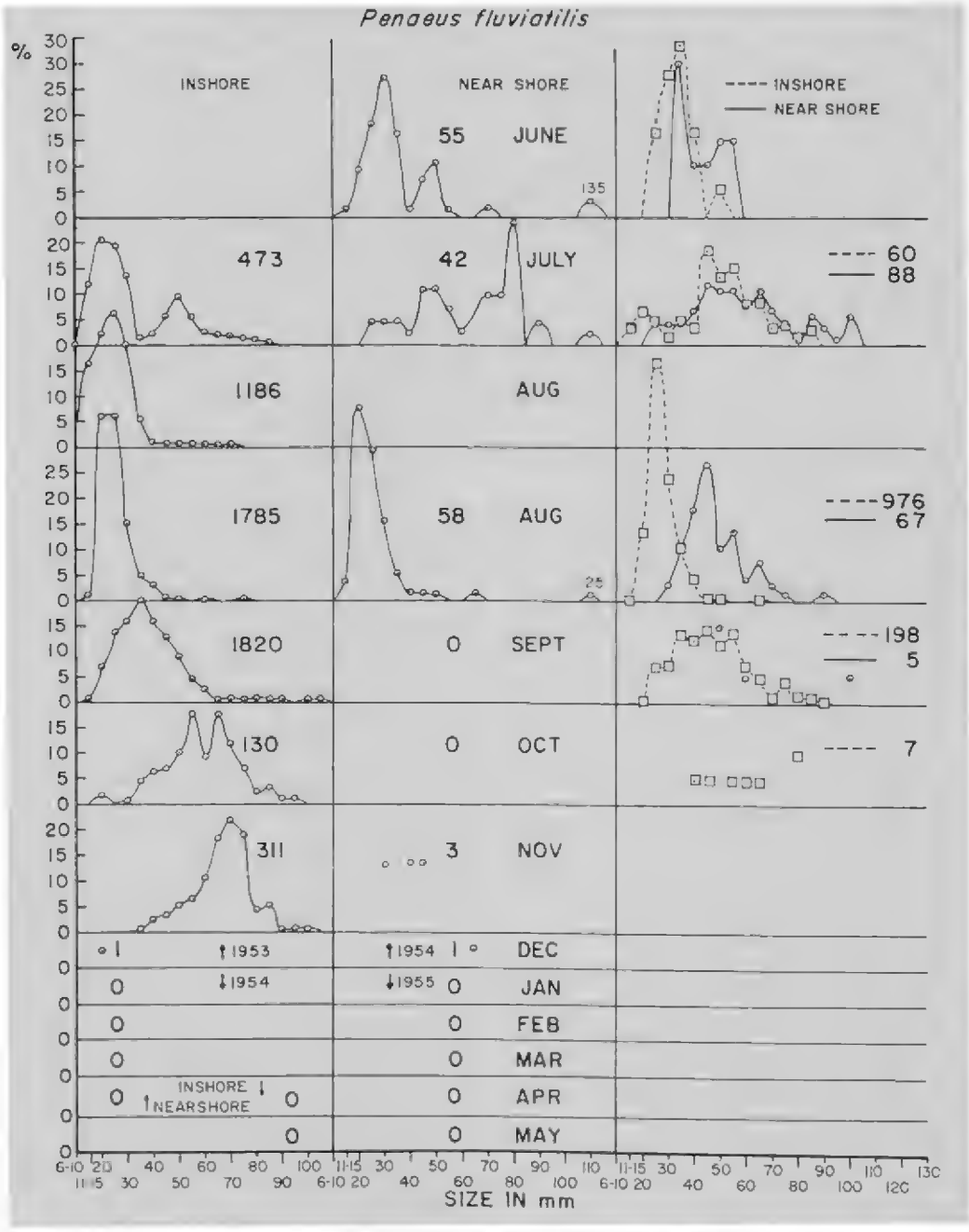

FIG. 6. Length-frequency diagrams by months of lengths of all white shrimp taken in nearshore and inshore areas.

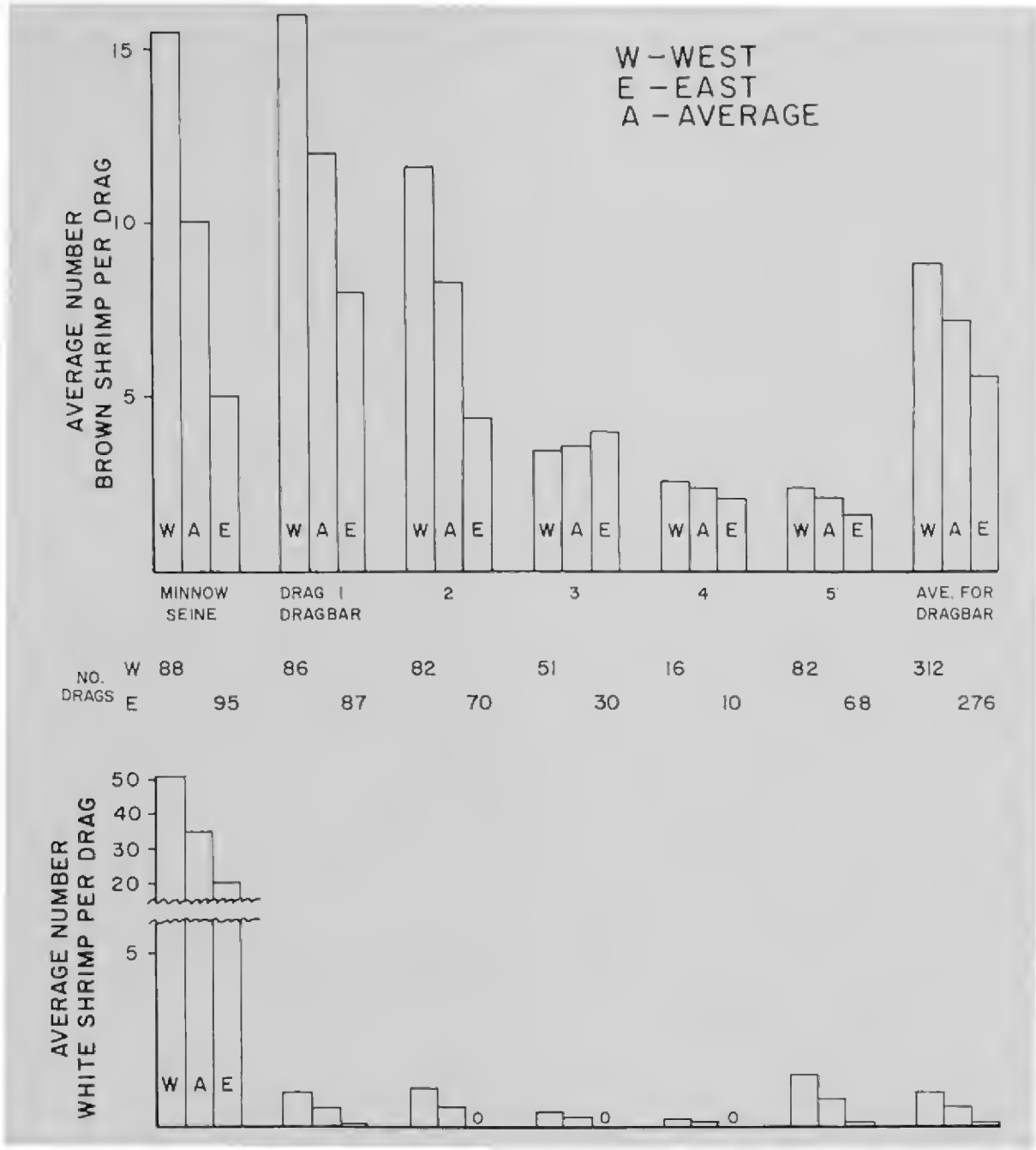

FIG. 7. Average numbers of shrimp taken at shore stations. Top—*P. aztecus*, bottom—*P. fluviatilis*, middle—No. of drags at each location. The minnow seine was used nearest shore. Drag 1 began in about 2 to 2½ feet of water and continued to about 3 feet. Drag 2 began where drag 1 stopped and continued to deeper water, etc. Drag 4 was at the last sandbar. Drag 5 was about one mile straight offshore from drag 4. Each drag was of 3-minute duration at 2 knots.

The average number of white shrimp taken per seine haul at each station varied from none at Station m to 135.5 at Station d (Table 9, Loesch, 1962). Western shore stations yielded an average of 50 shrimp per haul and eastern shore stations averaged but 5.5. The majority of the shrimp on both sides were taken at the more northerly stations, e, d, and h.

Because the young white shrimp tended to be concentrated at the extreme shoreward edge of the water, data obtained from the drag-bar net could not be used to estimate numbers of available shrimp as was done in the case of the brown shrimp. It is apparent, nevertheless, that white shrimp were available in approximately the same numbers as were brown shrimp, but for a much shorter period of time (including only late July, August, and September).

GROWTH RATES

Results of statistical analyses of the samples of Mobile Bay shrimp by the methods of Hubbs and Hubbs (1953) modified by Williams (1955), based on samples of shrimp

taken from the twelve bay stations, the twelve inshore stations, and the ten nearshore stations, are depicted graphically in Figs. 8 and 9.

Brown Shrimp

Early in the season, when shrimp first appear in the bay, intraspecific competition for food and space is not as severe as it is in the middle of the summer after the waters have become more densely stocked. The mean size of the young shrimp increased from 20 mm in April to about 40 mm a month later. Thereafter, the mean remained between 30 and 50 mm as long as shrimp were found in the nearshore area. The increase in mean length the first month may have occurred because shrimp were entering a hitherto unpopulated area; later, the mean remained almost constant (Fig. 5) because larger shrimp were leaving the sampled area at about the same rate as smaller shrimp were entering the area.

Even while shrimp are growing, a continuous recruitment of young shrimp and an emigration of slightly larger shrimp would produce a population in a given area with a static mean and mode. Only when there is no recruitment and little emigration can the mean or the mode be used to estimate growth. When there is continuous recruitment and emigration, better estimates are obtained by using extremes: in winter, after recruitment ceases, the lower extremes give an estimate of growth; during the summer, with the continuous influx of the new crop of young shrimp, the higher extremes are more indicative of growth.

By using the lower extremes, that is, the smallest shrimp, growth estimates for the winter months are 13 mm in 1954 and 18 mm in 1955 (Figs. 8, 10). Water temperatures ranged from 10 C to 25 C.

From February to April 1954 the modal length increased from 83 to 118 mm, or 35 mm in two months. For the same months in 1955 the modal increase was from 78 to 118 mm or 40 mm in two months. This compares well with the growth estimates made from the size increase of the smallest individuals taken during this period.

Estimates of spring growth of old shrimp, also using the lower extremes, were 35 mm and 30 mm per month for 1954 and 1955, respectively. An estimate of growth of young shrimp, using larger extremes, from April to May, 1954 was 50 mm. There were only four shrimp in the small mode of the April sample, however, and this estimate is open to question. Growth estimates based on much larger samples in the summer months, and using the largest shrimp as growth indicators, were 30 mm per month in 1954 and 43 mm per month in 1955 for the months of May and June (Figs. 8, 10).

Assuming that, with optimum growing conditions such as are probably found when shrimp first arrive in the growing areas, the growth rate is 35 mm per month, shrimp arriving in April would be approximately 100 mm in June and 200 mm in September. It is possible, then, that during one summer a brown shrimp may mature and spawn in

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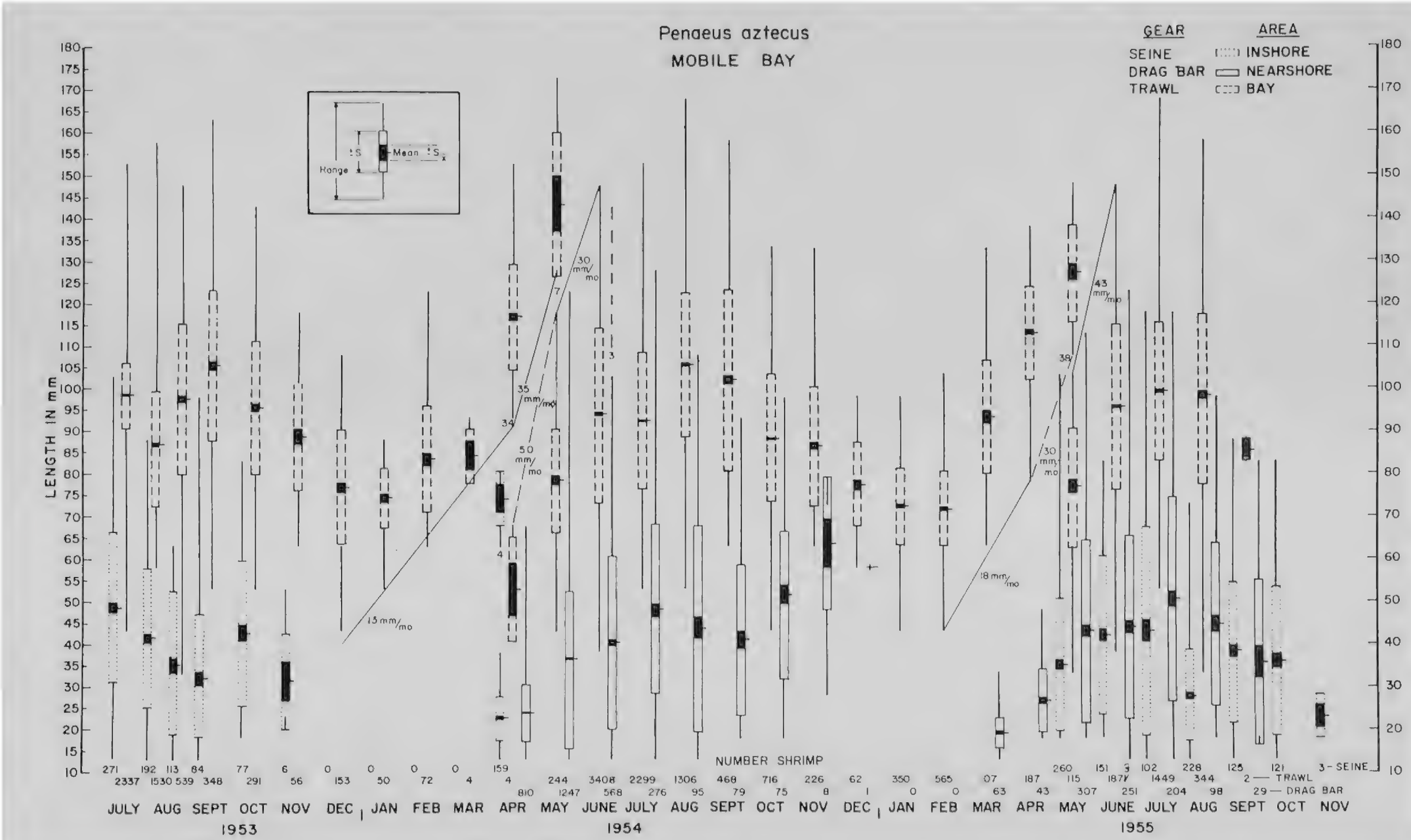
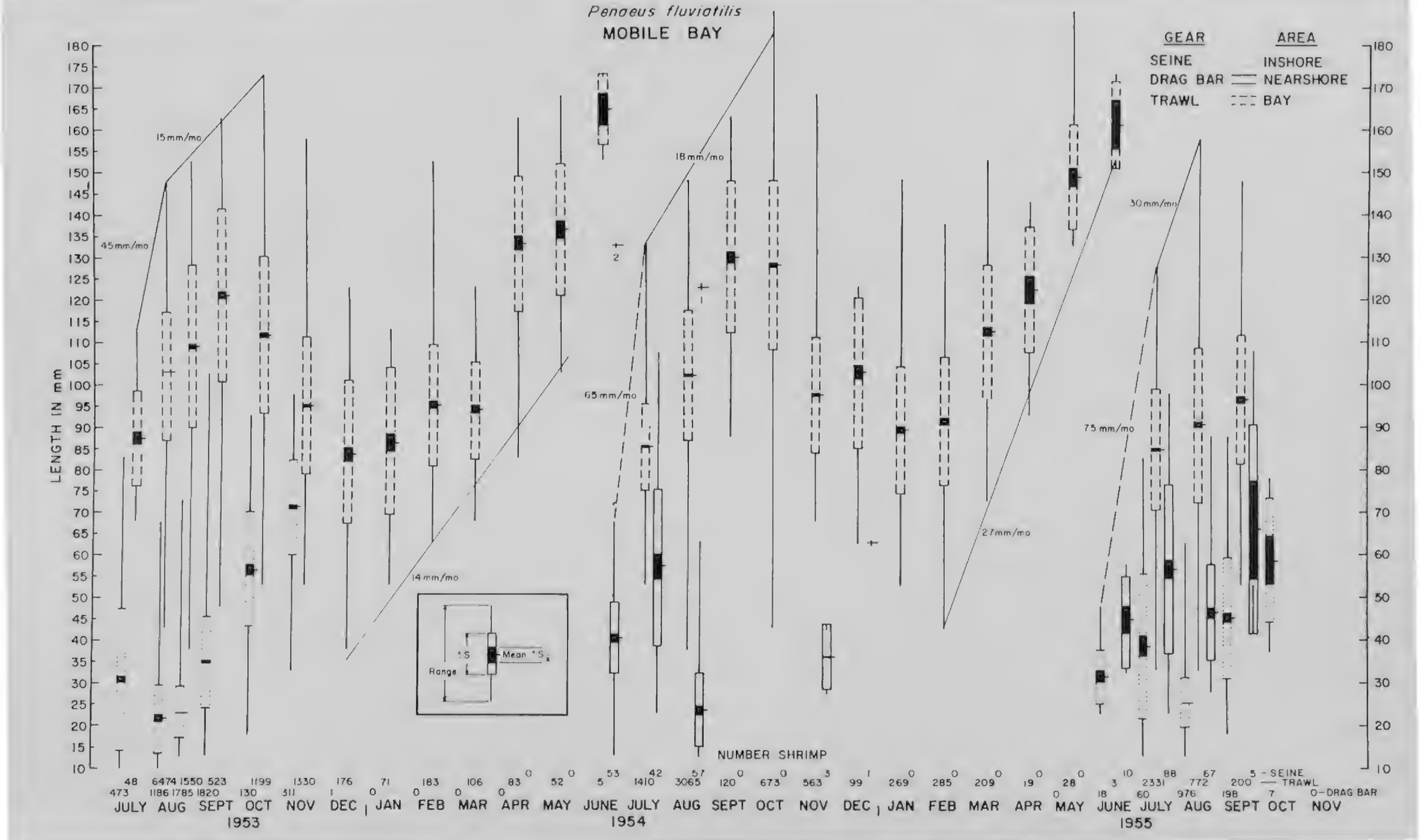
FIG. 8. Graphic representation by months of all brown shrimp taken in Mobile Bay by all types of gear. A minnow seine was used in inshore areas; a 30-inch drag-bar net, in nearshore areas; and a 16-foot trawl in the bay. All shrimp taken by one gear during the month are lumped. A slash designates the mean ($\bar{x}$). The standard error of the mean ($S\bar{x}$) is designated by a solid rectangle. Standard error (S) is shown by a hollow rectangle. The range is shown by a line. Diagonal lines connecting extremes may indicate growth. The numbers of shrimp taken in a month by a specific gear is given at the bottom of the figure.



Penaeus aztecus
MOBILE BAY
GEAR
SEINE
DRAG BAR
TRAWL
AREA
INSHORE
NEARSHORE
BAY
LENGTH IN mm
Range
Mean
NUMBER SHRIMP
JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1953
1954
1955
2 — TRAWL
29 — DRAG BAR
3 - SEINE

Penaeus fluviatilis

MOBILE BAY



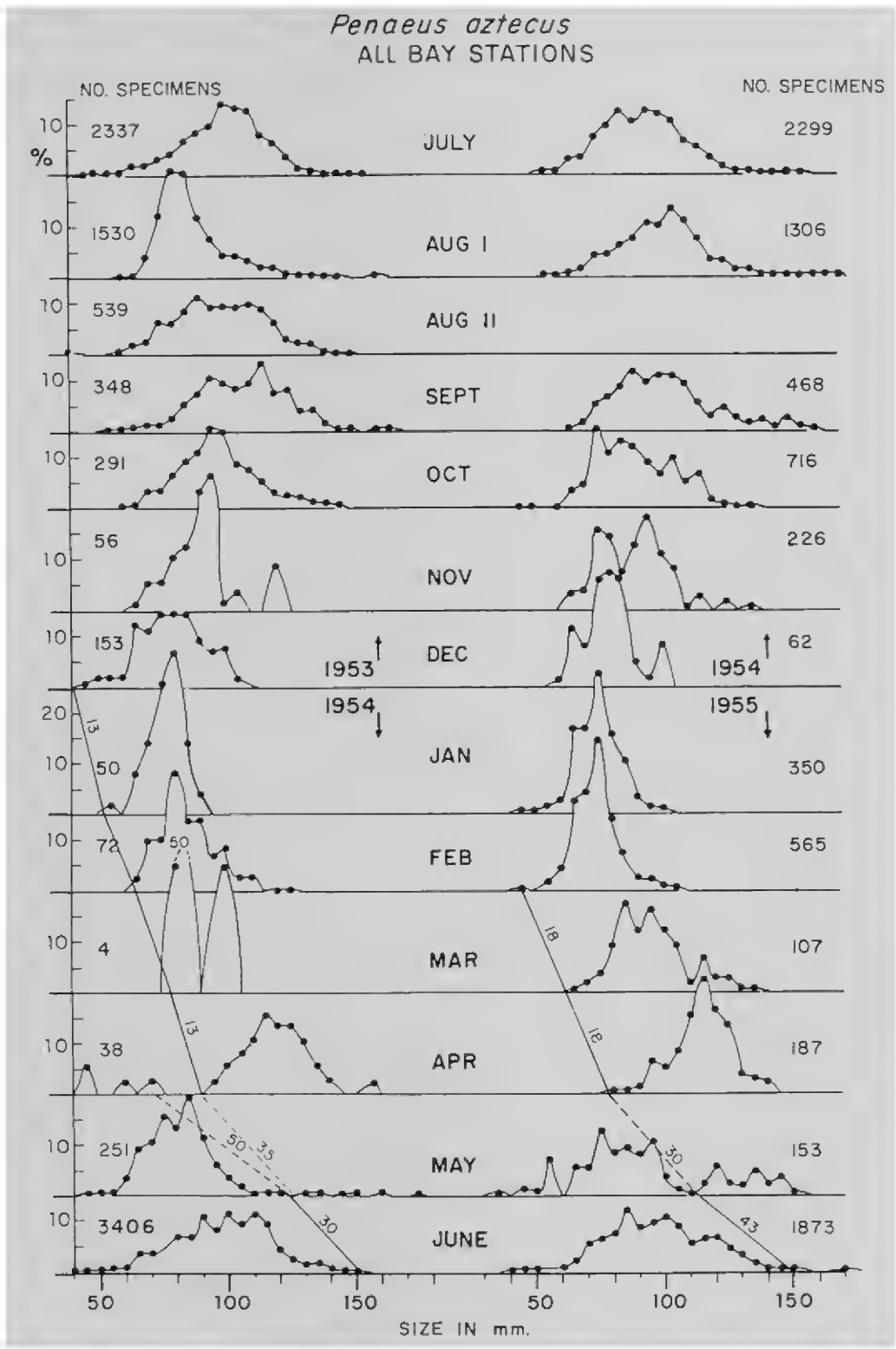


FIG. 10. Length-frequency diagrams by months of all trawl-caught brown shrimp in bay samples. Lines connecting extremes indicate growth.

as little as five or six months after arrival in Mobile Bay. Shrimp first appearing in the bay in March and April may thus produce a second spawning peak in the fall.

Only in June, July and August were above-average numbers of brown shrimp taken by trawl (Table 11, Loesch 1962). There was a general decrease in numbers of shrimp taken from October to March or April, a small increase in May, a great increase in June followed by a gradual decrease until September, and no change or a slight increase in

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FIG. 9. Graphic representation by months of lengths of all white shrimp taken in Mobile Bay by all types of gear. A minnow seine was used in inshore areas; a 30-inch drag-bar net in nearshore areas; and a 16-ft. trawl in the bay. All shrimp taken by one gear during the month are lumped. The numbers of shrimp taken in a month by a specific gear is given at the bottom of the figure. A slash designates the mean ($\bar{x}$). The standard error of the mean ($S\bar{x}$) is designated by a solid rectangle. Standard error (S) is shown by a hollow rectangle. The range is shown by a line. Lines connecting the extremes may indicate growth.

October. When there is an increase in October it may be the result of a second spawning peak, or it may be the result of an increased survival rate caused by a reduction in competition coincident with the emigration of the larger shrimp to the deeper waters and the Gulf.

White Shrimp

The first young white shrimp appeared in Mobile Bay in early June. The largest numbers were found in August, and in late November or early December large numbers left the bay, probably in schooled migrations (Table 8, Loesch 1962).

The same types of procedures and graphs used in estimating growth of brown shrimp were also used for white shrimp. Winter growth estimates, using lower extremes, from December 1953 to May 1954 were 14 mm per month, and from February to May 1955, 27 mm per month (Figs. 9, 11). The mean and modal length of trawl-caught white

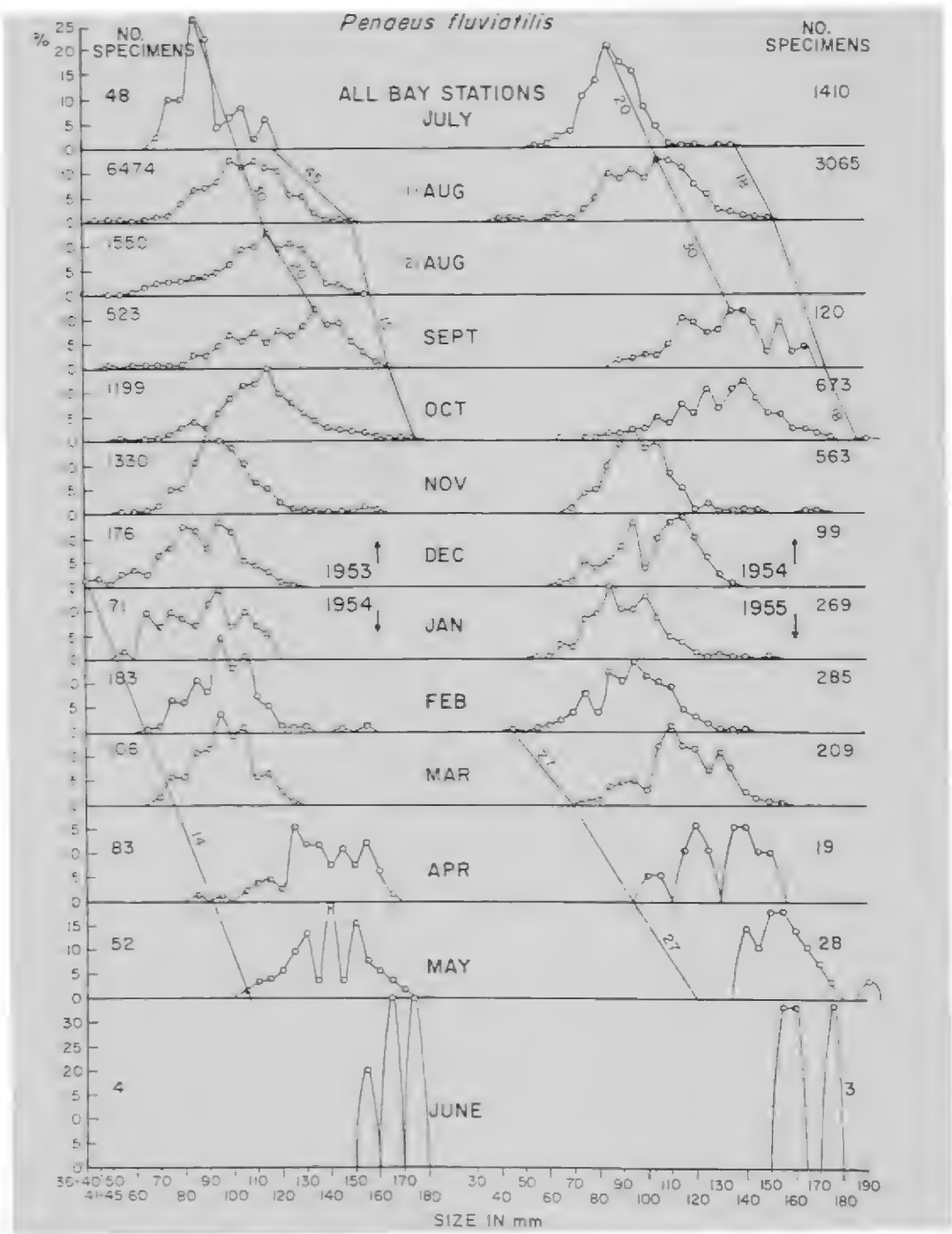

FIG. 11. Length-frequency diagrams by months of all trawl-caught white shrimp in bay samples. Lines connecting extremes indicate growth.

shrimp advanced from 93 mm in February 1955 to 154 mm in May, or about 20 mm per month. In 1954 the advance was from 98 to 143 mm from March to May, or about 23 mm per month.

Growth rates, using upper extremes, of the young white shrimp were 19 mm per month from July to September 1954, and 30 mm per month from July to August 1955 (Fig. 9). By using the modes in July, August, and September (1953 and 1954), growth estimates of 20 and 30 mm per month were obtained (Fig. 11).

It is well known among Mobile Bay commercial shrimpers that in July large numbers of white shrimp just under 100 mm in length suddenly appear in the trawls. At no time during this sampling program were young white shrimp found anywhere in the bay before June. In June no young white shrimp were taken in the trawl but shore and nearshore gear produced white shrimp smaller than 70 mm. However, shrimp 110 to 115 mm (1953), 130 to 135 mm (1954), and 125 to 130 mm (1955) were found in July. The sampling program had not begun by June 1954, but for the two subsequent years the maximum length of shrimp caught by trawl in July was 65 and 75 mm more than the maximum length of shrimp taken by seine or drag-bar net in June of the same year (Fig. 9). Different types of gear were used to capture the shrimp at the different stages of their development, so caution should be exercised in using this estimate.

From September or October through January the mean and modal length of white shrimp decreased (Fig. 9). If it is assumed that change in mean or modal size indicates growth, a negative growth is obtained. This obviously is impossible. A logical explanation is that larger individuals are leaving the bay by emigration into the Gulf and by fishing pressure concentrated in the areas immediately adjacent to the Gulf.

After attaining a peak in late July and August, white shrimp abundance in Mobile Bay decreased in September (Table 11, Loesch 1962). In September large numbers of shrimp moved from the shallower to the deeper parts of the bay, there to form the second peak in abundance in October and November. The seasonal distribution of commercial trawl catches reflected these peaks. Gunter (1950) found similar peaks to occur in Texas, with the month of low abundance there being October.

Gunter (1950) also postulated that the growth rate of white shrimp was such that all growth was practically completed in one warm season. Lindner and Anderson (1956) found a differential growth rate, with the larger shrimp growing at a slower rate, and with maturation reached at about 150 mm. With such a growth rate, it is doubted that white shrimp could mature and spawn in their first summer.

A summary of monthly growth rates as estimated by various workers follows:

Investigator	*Avg. growth per month*	*Method used*
Lindner and Anderson (1956)	10 mm (White)	Tagging 170-mm shrimp
Lindner and Anderson (1956)	30 mm (White)	Tagging 100-mm shrimp
Pearson (1939)	20 mm (White)	Aquarium growth of juveniles
Viosca (1920)	25 mm (White)	Unknown, juveniles

Gunter	(1950)	30 mm (White)	Length-frequency studies of field samples, juveniles
Williams	(1955)	36 mm (White) 46 mm (Brown)	Length-frequency studies of field samples, juveniles
Johnson and Fielding	(1956)	57 mm (White)	Pond growth, juveniles
Loesch (as reported in this paper)		13–27 mm (White) 12–35 mm (Brown)	Length-frequency studies of winter field samples, juveniles.
		18–31 mm (White) 24–43 mm (Brown)	Length-frequency studies of summer field samples, juveniles.
		65 mm (White) 50 mm (Brown)	Length-frequency studies of spring field samples, juveniles.

Pink Shrimp

During the entire survey, only 262 pink shrimp were caught in Mobile Bay. These were all taken from October to May (Table 12, Loesch 1962). All pink shrimp caught in October and November were taken in the lower end of the bay.

In the 1953–54 winter season, 62 pink shrimp were caught in the sampling trawls; in the 1954–55 season 200 were taken. In 1956, according to U.S. Fish and Wildlife Service statistics, Mobile Bay produced 475 pounds of pink shrimp, all in May. In March 1957 examination of several commercial catches of shrimp from Mobile Bay showed pink shrimp comprising about one-third of the catch. More than 34,000 pounds of pink shrimp were caught in Mobile Bay in 1957. The following year 2,086 pounds of pink shrimp were reportedly caught in Mobile Bay. Apparently the presence of pink shrimp in large numbers is sporadic.

Conclusions

Movement of young brown shrimp into Mobile Bay extended from April to September, with some occurring as late as November. Such movement seemed to occur in waves or peaks. These waves may have been a reflection of spawning peaks of the 5- to 6-month-old shrimp after the summer season and the 7- to 8-month-old shrimp after the winter season. Shrimp appearing first in the nursery areas find little competition, grow rapidly, and form the first wave. As they leave the area, in the post-juvenile stage, another recruitment wave forms.

Similar movement of young white shrimp ranged from June to January, with the heaviest recruitment taking place in July through September. White shrimp recruitment also occurred in waves. Millions of young shrimp of both species were available at any given time throughout the summer months, and billions were available at the peak seasons.

Abundance of the very young shrimp varied with the type of habitat in which they occur. Young brown shrimp (15–70 mm) were concentrated in water 2 to 3 feet deep where there was attached vegetation. Young white shrimp (15–70 mm) were most abundant in water less than 2 feet deep containing large amounts of organic detritus, as

found on the western shores of Mobile Bay and at the most northerly station on the eastern side of the bay. Areas occupied do overlap at times and the recruitment waves of white and brown shrimp seemed to alternate. Since the preferred areas were somewhat distinct, it is probable that each species had different food habits or cover preferences implying that competition between species is not a major factor in abundance limitations.

Brown shrimp spawned in late summer grew 13 to 18 mm per month from November to April, and 30 to 35 mm per month from April to May. The apparent early summer growth rate of the March-spawned brown shrimp was 30 to 43 mm per month. Very young brown shrimp may grow as much as 50 mm per month. Even when a differential growth rate is considered, brown shrimp may attain spawning size in the six warm-weather months.

Young white shrimp appearing in the bay in July apparently grew 18 to 30 mm per month during the summer. The very young white shrimp may grow as much as 65 mm per month. They probably do not attain spawning size in one summer.

Young white shrimp recruited in September apparently grew 14 to 27 mm per month during winter months.

Acknowledgments

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Vertical Distribution of the Planktonic Stages of Penaeid Shrimp[1]

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Abstract

In an attempt to describe the vertical diurnal distribution of planktonic stages of penaeid shrimps, short research cruises into the Gulf of Mexico were made in June, July, September, and November 1963. The plankton was sampled systematically at a station 50 miles south of Galveston, Texas, where water depth approached 36.5 meters. Samples were obtained with a Clarke-Bumpus sampler at 4-hour intervals at each of three depths: 2, 18, and 34 meters. Bathythermograph casts were made prior to or at the completion of each collection.

During the first three cruises when temperature profiles and visual observations indicated a vertically stable water mass, catch data grouped for all stages indicated that planktonic penaeids were most frequent at and below mid-depth. Data arranged by developmental stage indicated, however, that protozoeal stages were found most frequently near the bottom whereas postlarval stages were at or above mid-depths. Each planktonic stage extended its distribution into the surface layer either just prior to or after darkness.

In November, when temperature profiles and visual observations indicated a vertically unstable water mass, planktonic-stage penaeids were more or less homogeneously distributed throughout the water column. There was no evidence of movement into the surface layer at night by any planktonic stage.

Introduction

Biologists at the Bureau of Commercial Fisheries Biological Laboratory in Galveston, Texas are engaged in a broad investigation of the seasonal as well as areal distribution and abundance of larval and postlarval penaeid shrimps in the northwestern Gulf of Mexico. Over the past two decades, studies of all phases of the life history of Gulf Penaeidae have received greater impetus as the commercial importance of many members of this family has increased. Prior to this period, information concerning young or larval penaeids in the Gulf of Mexico was restricted primarily to the work performed by Pearson (1939). He described the larval and postlarval stages of the white shrimp, *Penaeus setiferus*, and those of several other important penaeids occurring in the Gulf, including information on their growth and distribution as well. More recently, Dobkin (1961) outlined in detail the larval and postlarval stages of the pink shrimp, *Penaeus duorarum*, and Renfro and Cook (1963) described the early larval stages of the seabob, *Xiphopeneus krøyeri*. Very little information is available, however, concerning early stages in the life history of the brown shrimp, *Penaeus aztecus*, which in recent years has become the Gulf's most valuable commercial species.

It is generally believed that brown shrimp spawn in the open Gulf, sometimes as far as 110 miles offshore in depths to 110 meters. The eggs, slightly more dense than sea water, are deposited on the bottom. After hatching, the young planktonic shrimp develop through a series of three larval (nauplial, protozoeal, and mysis) and several postlarval

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stages. They enter the bays as advanced postlarvae where they grow rapidly to subadult size and subsequently migrate offshore to repeat their life cycle.

The movement of postlarval brown shrimp into estuarine nursery areas along the northwestern Gulf of Mexico appears to be a prerequisite for the production of their greatest biomass. Whether the planktonic stages are capable of extensive shoreward movement, whether water currents are largely responsible for their transport inshore, or whether both factors are important, is not known. Although Gurney (1924) and Koxon (1934) felt that the advanced stages of decapod larvae are not as much at the mercy of currents as might be supposed, the role of water currents in the distribution and survival of planktonic forms has been of considerable concern for a number of years. Colton (1959) provided evidence that the transport of planktonic fish eggs and larvae from the cooler waters of Georges Bank (Gulf of Maine) into the warmer Gulf Stream resulted in mass mortality. In a similar manner, water currents over the continental shelf in the northwestern portion of the Gulf of Mexico may be of considerable importance in the survival of planktonic penaeids. Because current direction and velocity may vary with depth, the importance of water currents can be properly assessed only after the position of the organism within the water column is known. This paper presents the results of four attempts to determine the vertical distribution of the planktonic stages of penaeid shrimp in the water column.

Materials and Methods

Short cruises with the Laboratory's research vessel were conducted in June, July, September, and November 1963 to a station 50 miles south of Galveston where the water depth approaches 36.5 meters (Fig. 1). Results of sampling in 1961 and 1962 had indicated that planktonic stages of penaeid shrimp usually could be found at this station at these times.

Plankton collections were made with a Clarke-Bumpus sampler whose frame was enlarged so that two nets could be mounted instead of one (Fig. 2). The mouth of each net had a cross-sectional area of 120.6 cm^2. Nets of No. 3 bolting silk (aperture 0.33 mm) were employed throughout the first three cruises, whereas, No. 2 nylon nets (0.36 mm) were used for the November collections. Since the samplers could be opened and closed at the desired depths, contamination with material from other depths while lowering or retrieving the gear was believed negligible.

Sampling covered 36 hours during the first cruise and 44 hours during each of the other three. Collections were made at 4-hour intervals at three depths: 2, 18, and 34 meters. Although samples were not taken at all depths simultaneously, every series was completed within an hour. Towing speed varied between 2 and 3 knots on a circular course around an anchored buoy. Bathythermograph casts were made either prior to or at the completion of each tow.

Plankton samples were preserved in 10% "buffered" formalin. In the laboratory, each sample was examined, and all penaeid larvae and postlarvae were removed, counted, and identified. Although four genera of shrimp were encountered (*Penaeus*, *Trachypeneus*, *Sicyonia*, and a few *Solencera*), analysis by individual genera was not attempted because of the small sample sizes.

Flow meters in the Clarke-Bumpus samplers were calibrated by the technique of

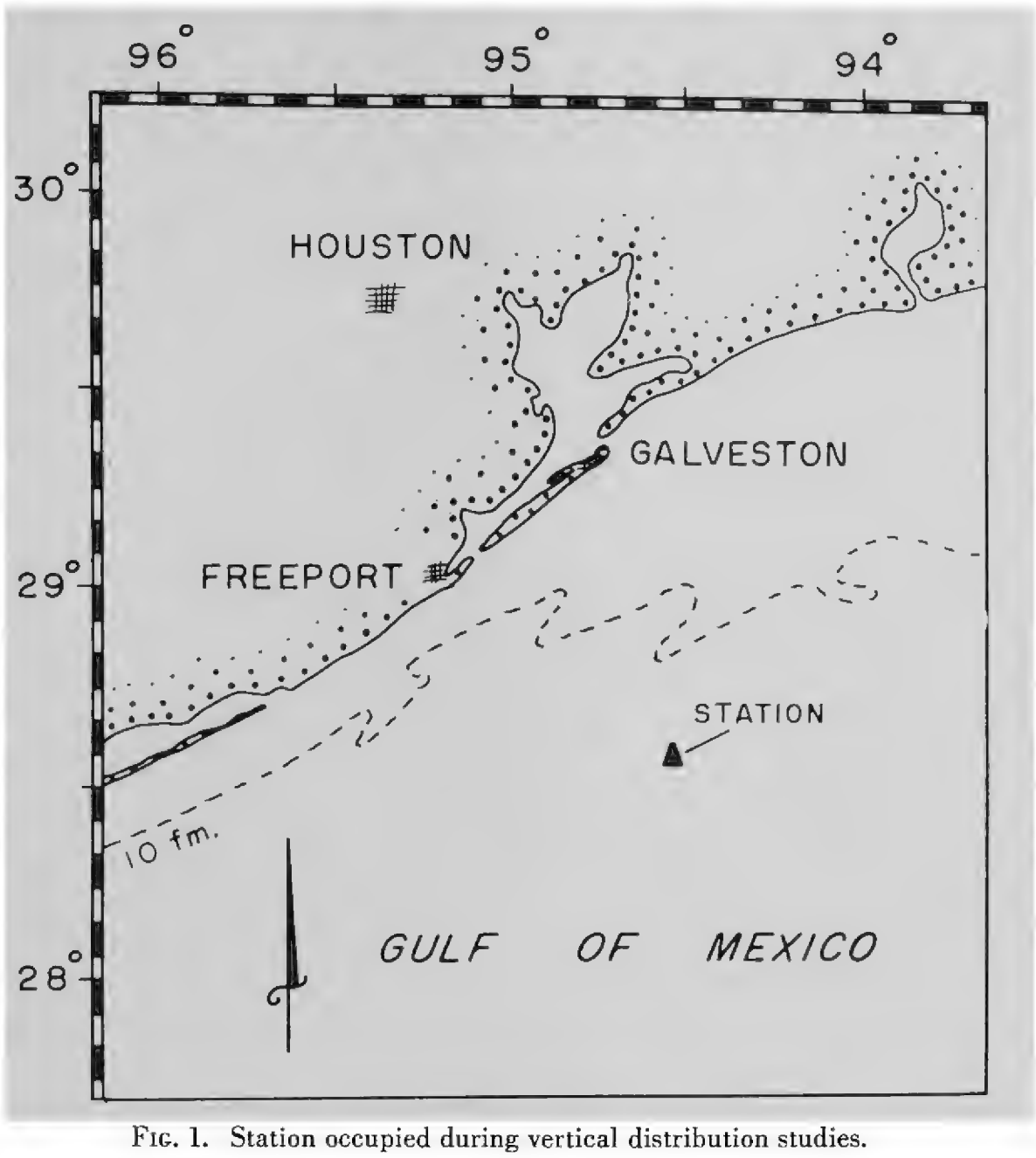

FIG. 1. Station occupied during vertical distribution studies.

Ahlstrom (1948). At speeds varying from 2 to 3 knots, each sampler filtered approximately 10 m^3 of water per 10-minute tow. Catch per tow as reported here consists of numbers per 20 m^3 of water filtered.

Data obtained during each cruise are presented by number, time, and depth of tow in Tables 1–4.

General Depth Distribution

Although the abundance of planktonic stages varied during the June, July, and September cruises, the observed depth distributions of planktonic penaeids were similar (Fig. 3). Data grouped by stages show that immature (planktonic) penaeids were 2 to 4 times more abundant at the 18- and 34-meter depths than at the 2-meter depth. Protozoeal and mysis stages were found frequently in the deeper portions of the water column while postlarval stages occurred most frequently in the upper portion. The observed vertical distribution of the protozoeal and mysis stages agrees with the findings of Russell (1925, 1928) and Heegaard (1953). Russell, who dealt with larvae of several kinds of decapods, found the major concentrations of larvae nearer the bottom than the surface. Heegaard, who reported on larval *P. setiferus*, observed a similar depth distribution. The data presented in Fig. 3 also indicate that the vertical distribution of the planktonic stages is reversed as the shrimp grow from the protozoeal stage to the postlarval

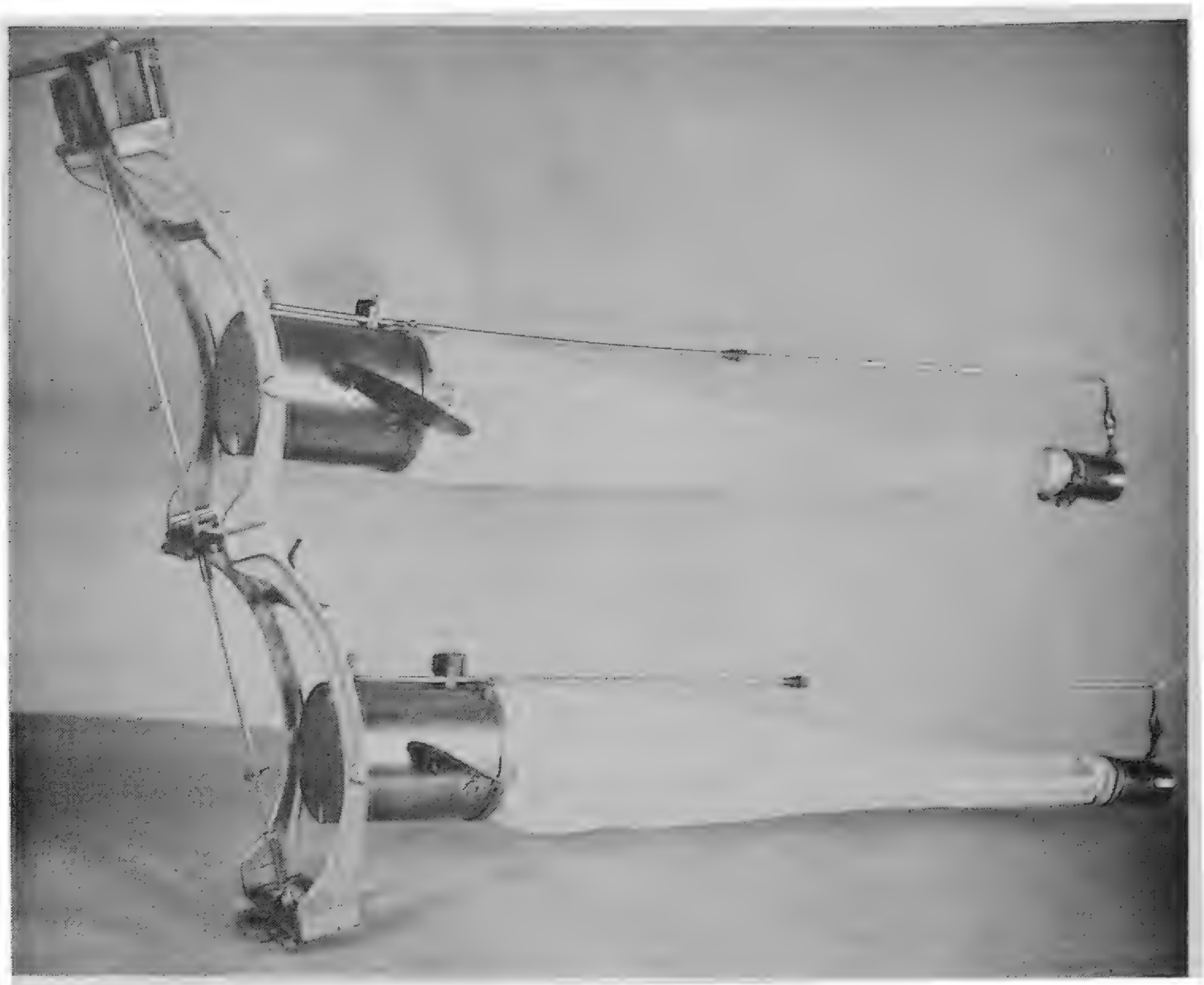

FIG. 2. Clarke-Bumpus sampler used in vertical distribution studies.

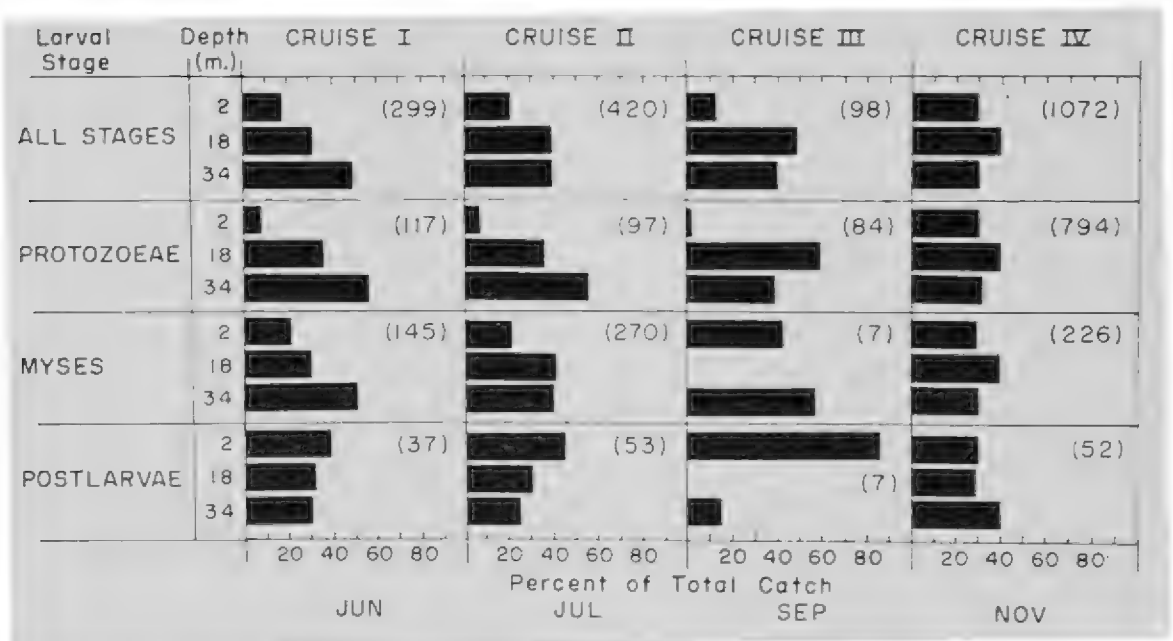

FIG. 3. Depth distribution of immature (planktonic) penaeids.

stage. This reversal is probably related to the animal's increasing mobility permitted by the development of the swimmerets.

The results of the November cruise differed considerably from those of the three previous cruises. Neither the grouped nor the individual-stage data showed any marked differences in depth distribution. Planktonic penaeid forms appeared to be uniformly distributed throughout the water column.

Significance of Temperature

Temperature profiles indicate that a well-defined discontinuity layer was present during the first three cruises, whereas isothermal conditions prevailed within the entire water column in November (Fig. 4). Although measurements of light penetration in the water column were not made, visual observation indicated that the water was extremely clear in June, July, and September but relatively turbid in November. From these observations (temperature profiles and water clarity) it appears that during the first three cruises the water mass was vertically stable with no evidence of vertical mixing, whereas in November it was vertically unstable with vertical mixing. The differences in depth distribution of the planktonic penaeids noted between the first three cruises (June, July and September) and the fourth cruise (November) can be attributed, in part, to the vertical mixing observed in November.

Evidence of Diurnal Migration

Similar short-term changes in the vertical distribution of each planktonic stage were noted in June, July, and September, although the scarcity of planktonic forms and the frequency of non-productive tows make the results of the September cruise of little significance. To illustrate this similarity, the data for each stage were grouped on a 24-hour basis, and average catches were determined for each hour and depth. The results, shown as the percentage of the total hourly catch by depth, are presented in Fig. 5.

These data indicate that various stages of planktonic penaeids do migrate vertically. All stages extended their distribution into the surface layer as darkness descended. The mysis and postlarval stages, however, appeared to migrate at an earlier hour and to remain within the layer longer than did protozoeal stages. These results agree with the

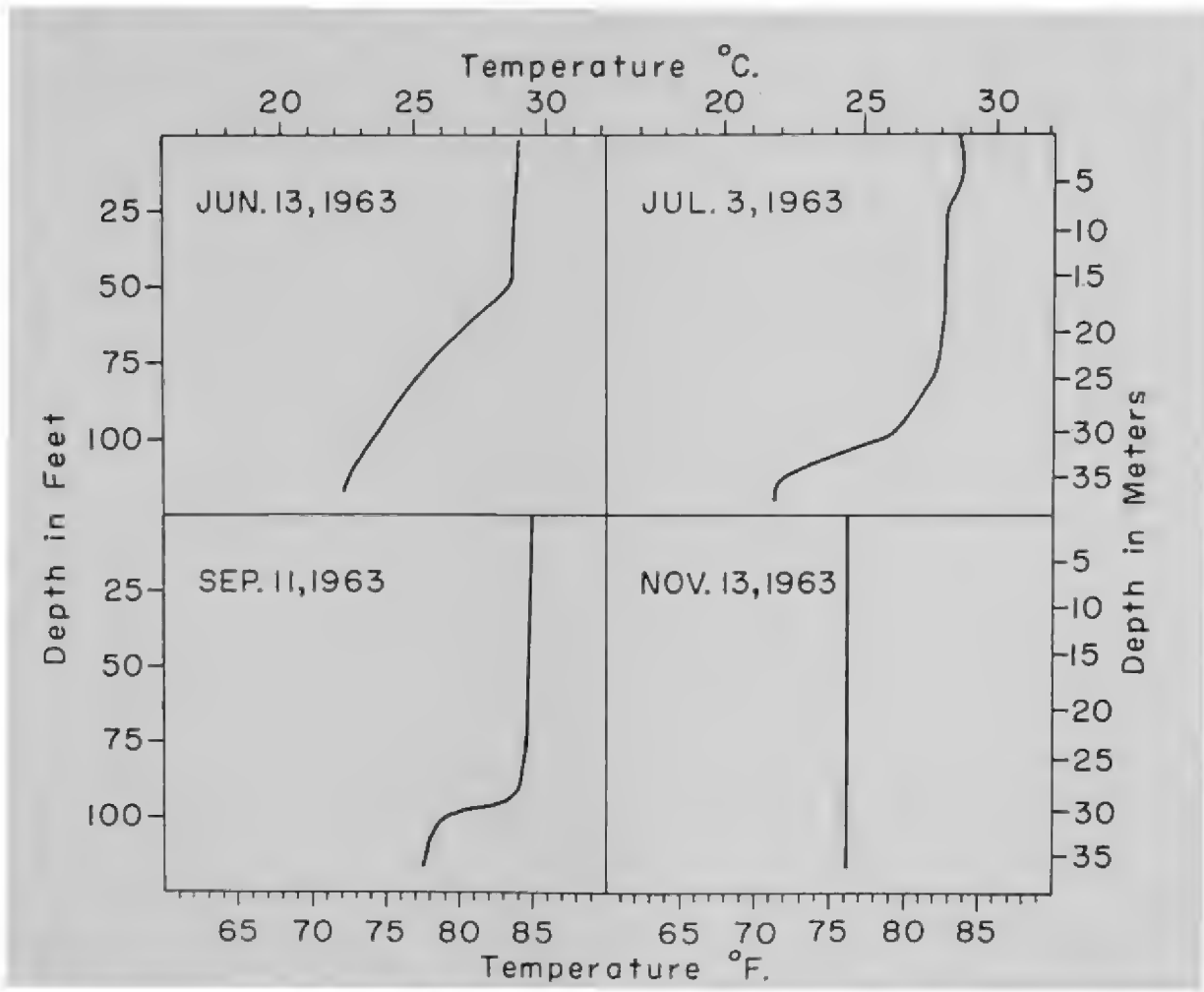

Fig. 4. Temperature profiles at sampling station during vertical distribution studies.

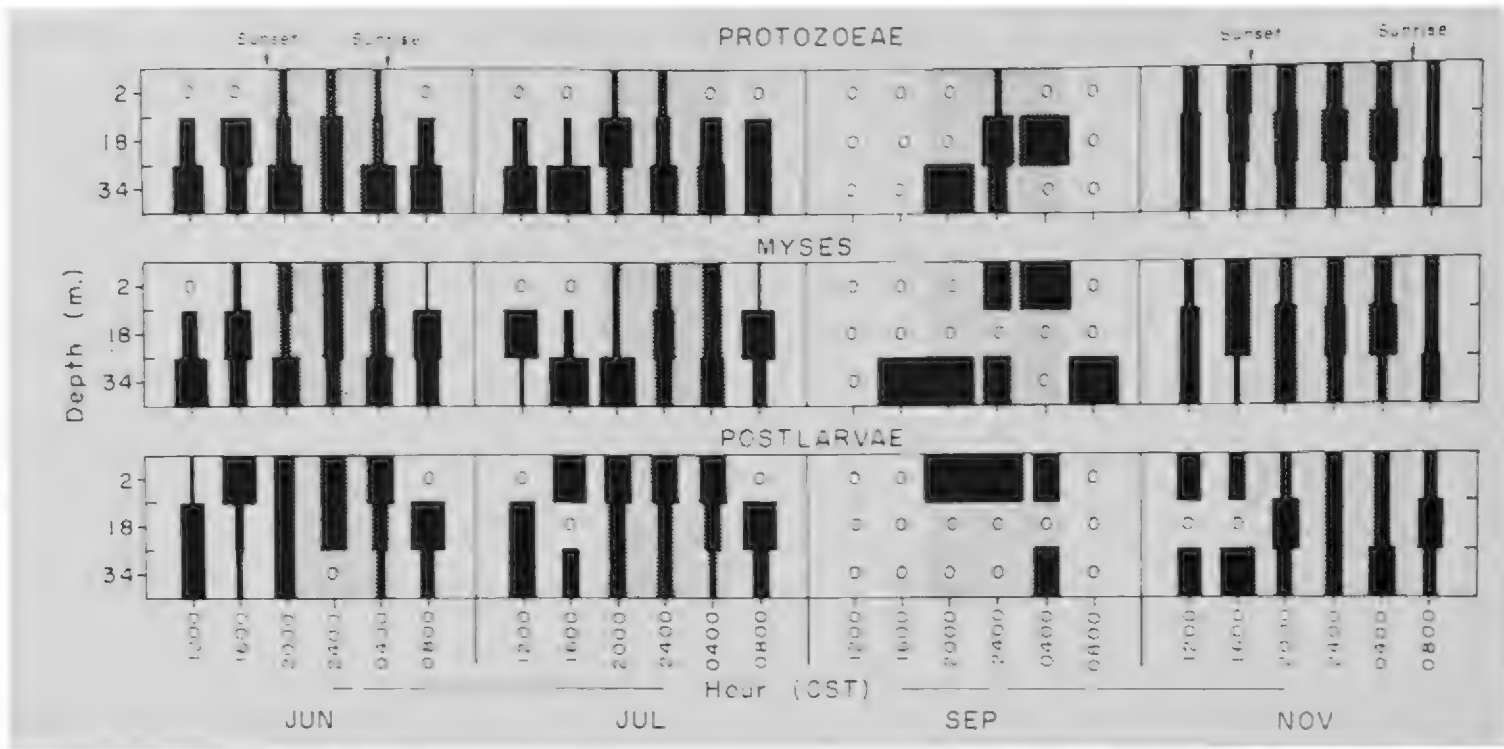

FIG. 5. Variations in the vertical distribution of immature (planktonic) penaeids over a 24-hour period.

findings of Russell (1928) who reported that decapod larvae, in general, extended their distribution into the surface layer with the advent of darkness.

November data gave no evidence of a diurnal migration by any planktonic-stage penaeid. The organisms were, relatively speaking, evenly distributed throughout the water column, probably as a result of the aforementioned vertical mixing.

AVERAGE CATCHES, NIGHT VS. DAY

After all data were grouped by planktonic stage and depth, the average catches during night (2000–0400 CST) and day (0800–1600 CST) were determined for each cruise (Tables 1–4).

TABLE 1

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, June 12–14, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	Total no.	Total samples	Per cent of total	No. per tow
All stages	2	14	16	11	2	1	8	6	15	14	2	89	10	16	8.9
	18	13	32	10	16	15	11	22	10	28	29	186	10	34	18.6
	34	45	22	36	14	26	7	37	21	37	31	276	10	50	27.6
	Total	72	70	57	32	42	26	65	46	79	62	551	30	100	18.4
Protozoeae	2	2	3	3	0	0	0	2	6	0	0	16	10	7	1.6
	18	7	19	1	5	5	6	11	5	7	7	73	10	32	7.3
	34	22	14	12	5	9	4	19	14	26	14	139	10	61	13.9
	Total	31	36	16	10	14	10	32	25	33	21	228	30	100	7.6
Myses	2	10	13	4	2	0	1	4	7	8	0	49	10	19	4.9
	18	4	12	9	9	5	3	11	5	16	14	88	10	34	8.8
	34	22	8	23	6	12	2	17	7	11	16	124	10	47	12.4
	Total	36	33	36	17	17	6	32	19	35	30	261	30	100	8.7
Postlarvae	2	2	0	4	0	1	7	0	2	6	2	24	10	39	2.4
	18	2	1	0	2	5	2	0	0	5	8	25	10	40	2.5
	34	1	0	1	3	5	1	1	0	0	1	13	10	21	1.3
	Total	5	1	5	5	11	10	1	2	11	11	62	30	100	2.1

TABLE 2

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, July 3–5, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
All stages	2	9	10	15	1	0	4	2	24	13	0	0	4	82	12	20	6.8
	18	15	32	22	10	33	9	7	5	13	15	2	1	164	12	39	13.7
	34	8	27	35	9	9	49	7	18	7	0	0	5	174	12	41	14.5
	Total	32	69	72	20	42	62	16	47	33	15	2	10	420	36	100	11.7
Protozoeae	2	1	5	0	0	0	0	0	0	0	0	0	0	6	12	6	0.5
	18	8	9	7	2	0	3	1	0	4	0	1	0	35	12	37	2.9
	34	3	19	11	2	3	13	0	1	1	0	0	3	56	12	57	4.6
	Total	12	33	18	4	3	16	1	1	5	0	1	3	97	36	100	2.7
Myses	2	6	5	13	1	0	0	2	18	7	0	0	0	52	12	19	4.3
	18	7	22	13	8	29	6	3	5	9	9	1	1	113	12	42	9.3
	34	4	7	23	5	3	33	7	16	6	0	0	1	105	12	39	8.7
	Total	17	34	49	14	32	39	12	39	22	9	1	2	270	36	100	7.5
Postlarvae	2	2	0	2	0	0	4	0	6	6	0	0	4	24	12	45	2.0
	18	0	1	2	0	4	0	3	0	0	6	0	0	16	12	30	1.3
	34	1	1	1	2	3	3	0	1	0	0	0	1	13	12	25	1.1
	Total	3	2	5	2	7	7	3	7	6	6	0	5	53	36	100	1.5

TABLE 3

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, September 10–12, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
All stages	2	1	4	2	0	0	0	2	1	1	0	0	0	11	12	11	0.9
	18	0	47	1	0	0	0	0	1	0	0	0	0	49	12	50	4.1
	34	4	29	0	1	0	0	2	0	1	0	0	1	38	12	39	3.2
	Total	5	80	3	1	0	0	4	2	2	0	0	1	98	36	100	2.7
Protozoeae	2	20	24	16	24	24	26	26	12	18	26	23	12	251	12	32	20.9
	18	0	47	1	0	0	0	0	1	0	0	0	0	49	12	58	4.1
	34	3	28	0	0	0	0	2	0	0	0	0	0	33	12	39	2.8
	Total	3	77	1	0	0	0	2	1	0	0	0	0	84	36	100	2.3
Myses	2	0	1	2	0	0	0	0	0	0	0	0	0	3	12	43	0.2
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0.0
	34	1	1	0	1	0	0	0	0	0	0	0	1	4	12	57	0.3
	Total	1	2	2	1	0	0	0	0	0	0	0	1	7	36	100	0.2
Postlarvae	2	1	1	0	0	0	0	2	1	1	0	0	0	6	12	86	0.5
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0.0
	34	0	0	0	0	0	0	0	0	1	0	0	0	1	12	14	0.1
	Total	1	1	0	0	0	0	2	1	2	0	0	0	7	36	100	0.2

The night-day catch ratios in June, July, and September were 1.6, 1.9 and 53.0 respectively. The comparatively large difference between September's average night and day catches, which yielded a high night-day catch ratio, was believed due to the sporadic occurrence and low density of penaeids in that month, not necessarily any inadequacy of the sampling technique. Larval abundance, as indicated from the results presented in Table 5, was considerably lower in September than during any of the other months. Consequently the variation in numbers of larvae between tows appeared more pronounced and resulted in seemingly biased data. The timing of this cruise apparently did not coincide with the second period of increased abundance of larvae which was expected

TABLE 4

Numbers of planktonic penaeids (per 20 m^3 of water filtered) in each sample, November 12–14, 1963

Planktonic stages	Depth in meters	Hours (CST) 2000	2400	0400	0800	1200	1600	2000	2400	0400	0800	1200	1600	Total no.	Total samples	Per cent of total	No. per tow
All stages	2	28	38	22	31	29	35	29	13	29	33	30	16	333	12	31	27.8
	18	48	46	49	21	20	23	27	19	34	38	51	48	424	12	40	35.3
	34	34	15	21	16	31	20	32	23	19	51	37	16	315	12	29	26.2
	Total	110	99	92	68	80	78	88	55	82	122	118	80	1,072	36	100	29.8
Protozoeae	2	0	2	0	0	0	0	0	0	0	0	0	0	2	12	3	0.2
	18	36	34	38	16	16	14	18	15	24	28	38	42	319	12	40	26.6
	34	24	11	15	14	21	14	20	12	14	39	28	12	224	12	28	18.7
	Total	80	69	69	54	61	54	64	39	56	93	89	66	794	36	100	22.1
Myses	2	5	10	5	6	4	8	3	0	11	5	6	3	66	12	29	5.5
	18	10	9	9	4	4	9	7	2	10	7	13	6	90	12	40	7.5
	34	8	2	3	2	10	4	9	9	4	11	8	0	70	12	31	5.8
	Total	23	21	17	12	18	21	19	11	25	23	27	9	226	36	100	6.3
Postlarvae	2	3	4	1	1	1	1	0	1	0	2	1	1	16	12	31	1.3
	18	2	3	2	1	0	0	2	2	0	3	0	0	15	12	29	1.3
	34	2	2	3	0	0	2	3	2	1	1	1	4	21	12	40	1.8
	Total	7	9	6	2	1	3	5	5	1	6	2	5	52	36	100	1.4

TABLE 5

Average number in night and day samples, all stages and depths combined by cruise

Period	Cruise I June	Cruise II July	Cruise III September	Cruise IV November
Night	22	15	5	29
Day	14	8	<1	30

on the basis of evidence from the synoptic plankton work conducted by laboratory personnel in 1961 and 1962. The night-day catch ratio was 1.0 in November.

Student's "t" test, applied to the mean values for the night and day catches, revealed significant differences at the 95% level during June and July but not in November. Due to the small sample sizes, tests were not made to compare the average night and day catches for either the individual stages or for the September data.

Summary

1. Four research cruises, one each in June, July, September, and November 1963, provided information on the vertical distribution of planktonic-stage penaeids at a 37-meter station in the northwestern Gulf of Mexico, 50 miles south of Galveston, Texas. On each occasion, samples were obtained with a Clark-Bumpus sampler towed at three depths (2, 18, and 34 meters) every four hours over a period of two consecutive days. Tows lasted ten minutes and were made on a circular course around a buoy anchored in about 37 meters of water.

2. In June, July, and September, the data grouped over all stages indicated that planktonic penaeids were most frequent at and below mid-depth (18 meters). Protozoeal stages occurred most frequently near the bottom and postlarval stages at or above mid-depth. This observation suggests that as larval development progresses, the depth of greatest

abundance decreases. In November, planktonic-stage penaeids were more or less uniformly distributed throughout the water column due to the "fall overturn."

3. Temperature profiles and visual observations of water clarity indicated that the water mass was vertically stable during the first three cruises, whereas it appeared to be vertically unstable in November. These seasonal differences in water conditions probably accounted for the change in vertical distribution of planktonic penaeids noted during the November cruise.

4. Each planktonic stage extended its distribution into the surface layer either just prior to or after the onset of darkness.

5. Statistical tests of average night and day catches (all stages and depths combined) in June, July, and November revealed significant differences in June and July but not in November. Average catches in June and July were approximately two times greater at night than during the day.

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Fish Stocks from a Helicopter-Borne Purse Net Sampling of Corpus Christi Bay, Texas 1962–1963[1]

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Abstract

A sampling operation (September 1962 to August 1963) with a helicopter-borne purse net has been completed. Strong seasonal variation was observed between the fall and the remaining three seasons. Biomass figures for the fall drops [107.8 lbs/acre (12.1 g/m^2) wet weight] averaged less than one half of each of the other seasons. The average biomass for the sampling period was 198.1 lbs/acre (22.3 g/m^2). In a series of 17 successful drops, the biomass per drop ranged from 44.8 (5.0) to 1573.7 lbs/acre (176.4 g/m^2). A total of 24 species was taken. The problems encountered were primarily concerned with sample frequency due to the delicate nature of flight operations.

Introduction

After considerable experimentation, a helicopter-borne purse net was developed for use in shallow bay areas of the Texas coast (Jones et al 1963). It was hoped that this net would function as an aid in estimating fish stocks and species composition of the bays.

The device was described in detail in the above paper but briefly, it approximated a right circular cylinder of nylon net of ¾ inch stretch mesh, 50 feet in diameter and 15 feet deep. It had a standard float line at the top and utilized a galvanized chain as a "lead line." The net was attached to a rigid circular frame of tubular aluminum by a series of electromagnets. The entire apparatus was carried by a helicopter to the drop area. When the electromagnet power supply was cut off, the net dropped into the water. The frame was flown back to the beach, leaving the net to be pursed from a boat standing by near the drop area.

Methods and Procedures

The sampling period ran from September 4, 1962, to August 14, 1963. The drops were conducted from one quarter to one mile north of the breakwater of Corpus Christi Naval Air Station, located on the south shore of Corpus Christi Bay, Texas. The sampling area ranged from 10 to 14 feet in depth, and the bottom was smooth and composed of soft mud and sand. Data represent this type of bay bottom rather than the whole bay which has differing environments.

Another sampling problem was encountered when the net sampled what may have been large schools of fish. Such prodigious catches tended to make the data statistically incompatible with the average drop. The proximity of the sampling area to the shoreline

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may have been a contributing factor toward the possibility of such a selective sample. Vast schools of menhaden and mullet have often been observed "migrating" along the shorelines of the bays. One particularly large catch of *Brevoortia patronus* [1440.8 lbs/acre (161.5 g/m^2)] was taken on August 5, 1963. In several of the tables included in this paper, this large catch was omitted in an attempt to keep the data in the same order of magnitude. If this catch were included, it would be roughly four times as great as the next largest catch (Table 3).

Each catch was returned in the net to the laboratory for processing. Wet weights were determined on a triple beam balance to the nearest tenth of a gram and standard lengths were taken to the nearest millimeter.

Temperatures were taken at the water's surface with a mercury-in-glass thermometer to the nearest tenth of a degree centigrade. Range of the water temperature was 12 to 30.5C (Table 1). Salinity samples were collected at the surface and titrated using the modified Mohr method. Salinities in the drop area ranged from 34.7 to 46.5 ppt. (Table 1).

Results, Fish Biomass

Of the twenty-four species of fishes taken by the helicopter drop net, 7 made up over 90% of the total catch (Table 2). Each species was considered by order of decreasing abundance. Table 3 shows monthly biomass data for the major species.

Brevoortia patronus Goode—Gulf Menhaden

The Gulf menhaden ranks far above other species in both number and weight. This menhaden was present in over 58% of samples taken. Four hundred eighty-six individuals were collected and a grand total of 69.5 lbs (31.6 Kg) was collected for the 17 drop series. These fish ranged in size from 90 to 250 mm with an average standard length of 139.8 mm.

Two authors (Gunter 1945—Aransas and Copano Bays, and Simmons 1957—Upper Laguna Madre) have indicated a tendency for *B. gunteri* to be more common than

Table 1

Salinities and temperatures taken on sample dates in Corpus Christi Bay

Date	Salinity ppt	Temperature C
September 4, 1962	.	29.3
October 10	36.45	29.3
December 19	39.10	16.0
January 4, 1963	35.40	14.5
February 19	34.70	12.0
March 1	34.85	15.0
March 6	34.95	16.0
March 17	46.23	30.0
May 24	43.36	26.5
June 11	41.70	27.0
July 5	41.23	28.0
July 8	41.78	30.0
July 10	42.30	30.5
July 24	.....	30.0
July 31	46.50	29.9
August 5	.....	30.0
August 14	43.68	30.0

TABLE 2

Percentage abundance by wet weight of the most common fishes captured (omitting the large *Brevoortia patronus* catch of August 5, 1963)

Species	Per cent of all catches	Cumulative per cent
Brevoortia patronus	36.0	36.0
Mugil cephalus	34.6	70.6
Cynoscion arenarius	5.9	76.6
Brevoortia gunteri	5.0	81.6
Leiostomus xanthurus	4.4	86.0
Galeichthys felis	2.6	88.7
Micropogon undulatus	2.2	90.9
Paralichthys lethostigma	1.6	92.6
Trichiurus lepturus	1.2	93.7
Bairdiella chrysura	0.4	94.1

B. patronus in the bays. While this may well be true for brackish and shallow water bay areas, the opposite seems to be true for the deeper waters of Corpus Christi Bay. These data show an over-whelming dominance of *B. patronus,* and support Reid (1955), who found *B. patronus* to be the dominant menhaden in East Bay, Texas.

There is agreement between workers (Gunter 1945, Roithmayr and Waller 1963, and Hildebrand 1963) that post-juvenile *B. patronus* are essentially absent from the bays in the winter (probably migrating to the Gulf to spawn, Suttkus 1956), and return again in the late spring or summer. These observations are supported by this investigation (Table 3).

Mugil cephalus LINNAEUS—STRIPPED MULLET

The second most abundant fish taken was the mullet. Together with *Brevoortia patronus* they made up over 70% by weight (Table 2) of all the fishes caught. Mullet were more evenly distributed over the sampling period than were menhaden. The striped mullet was taken in 70.6% of the drops. Size range for the mullet was 97 to 320 mm with an average standard length of 161.9 mm. One hundred twenty-nine individuals were taken and a grand total of 32.1 lbs (14.6 Kg) was collected for the 17 drops.

The largest catch was made on March 1, 1963. This catch probably represents a drop into a school. Gunter (1935, 1941, and 1945) reported that mullet were seldom taken in trawls in any number. Reid (1954) failed to take any in trawl hauls though they were common in shallow water seine hauls. Springer and Woodburn (1960) testified to the difficulty of capturing mullet that have reached a size of 80 mm. The helicopter drop net thus seemed to be quite effective for this species. The data herein would also seem to agree with Gunter's (1945) and Kilby's (1955) observation that few small mullet are found in the open bay (*i.e.*, those under 100 mm); except perhaps as they migrate from spawning points in the Gulf to shallow bay "nursery" areas (Kilby *op cit.*).

The abundance of *Mugil cephalus* is not surprising. It has been shown by Gunter (1941 and 1945), Joseph and Yerger (1956), Simmons (1957), Hellier (1962), and McFarland (1963) to be common in a variety of Gulf Coast habitats.

Table 3 shows the mullet to be essentially an all-year resident except possibly in the fall, when large emigrating schools are seen leaving the bay.

TABLE 3

Total weight in pounds per acre (grams/m^2 in parentheses) of each species and of all species at various dates through the years 1962 and 1963 by order of decreasing abundance

	Date of collection					
	Sept. 4	Oct. 10	Dec. 19	Jan. 4	Feb. 19	March 1
Brevoortia patronus	35.5(4.0)	.....	.....	.....	.....	.....
Mugil cephalus	.....	.....	100.8(11.3)	53.6(6.0)	143.2(16.1)	360.4(40.4)
Cynoscion arenarius	.....	58.1(6.5)	.....	112.0(12.6)	.....	.....
Brevoortia gunteri	.....	.....	.....	.....	.....	.....
Leiostomus xanthurus	5.8(.6)	28.8(3.2)	20.6(2.3)	.....	5.8(.6)	.....
Galeichthys felis	3.5(.4)	.....	.....	.....	.....	.....
Micropogon undulatus	.....	6.3(.7)	.1(.01)	.....	.....	.1(.01)
Paralichthys lethostigma	.....	.....	.....	.....	.....	.....
Trichiurus lepturus	.....	.....	.....	.....	.....	.....
Bairdiella chrysura	.....	.....	.....	.....	.....	12.3(1.4)
Citharichthys spilopterus	.....	.....	.....	.....	.....	.....
Polydactylus octonemus	.....	.....	.....	.....	.....	.....
Anchoa hepsetus	.....	.....	.....	.....	.....	.....
Others[1]	.....	.8(.1)	.....	.....	3.0(.3)	168.7(18.9)
Totals	44.8(5.0)	94.0(10.5)	121.5(13.6)	165.6(18.6)	152.0(17.0)	541.5(60.7)

	Date of collection					
	March 6	March 17	May 24	June 11	July 5	July 8
Brevoortia patronus	.....	162.0(18.2)	144.4(16.2)	.....	130.2(14.6)	107.7(12.1)
Mugil cephalus	68.0(7.6)	6.4(.7)	.....	104.4(11.7)	121.5(13.6)	34.8(3.9)
Cynoscion arenarius	.....	.2(.02)	.....	48.0(5.4)	.....	2.0(.2)
Brevoortia gunteri	.....	.....	.....	.....	116.9(13.1)	.....
Leiostomus xanthurus	.....	11.8(1.3)	.....	25.2(2.8)	6.9(.8)	10.5(1.2)
Galeichthys felis	.....	.7(.1)	.....	48.4(5.4)	5.8(.6)	7.2(.8)
Micropogon undulatus	.....	.....	1.2(.1)	21.2(2.4)	7.7(.9)	8.6(1.0)
Paralichthys lethostigma	.....	10.4(1.2)	.....	26.8(3.0)	.....	.....
Trichiurus lepturus	.....	.....	5.2(.6)	.....	.....	.....
Bairdiella chrysura	.....	.....	.....	3.1(.4)	.....	.....
Citharichthys spilopterus	.....	.6(.1)	.....	.2(.02)	.....	.5(.1)
Polydactylus octonemus	.....	.3(.03)	.6(.1)	.....	.....	.....
Anchoa hepsetus	.1(.01)	.4(.04)	.....	.1(.01)	.....	.....
Others[1]	.....	8.3(.9)	.....	5.3(.6)	28.7(3.2)	.....
Totals	68.1(7.6)	201.1(22.5)	151.4(17.0)	282.7(31.7)	417.7(46.8)	171.3(19.2)

	Date of collection				
	July 10	July 24	July 31	Aug. 5	Aug. 14
Brevoortia patronus	84.5(9.5)	219.2(24.6)	308.0(34.5)	1440.8(161.5)	147.2(16.5)
Mugil cephalus	.....	44.9(5.0)	136.0(15.2)	109.6(12.3)	.....
Cynoscion arenarius	.....	.....	.....	.....	.....
Brevoortia gunteri	70.3(7.9)	.....	.....	.....	.....
Leiostomus xanthurus	20.7(2.3)	.....	9.4(1.1)	17.1(1.9)	.....
Galeichthys felis	.....	2.5(.3)	14.2(1.6)	.....	15.6(1.7)
Micropogon undulatus	9.9(1.1)	.....	15.5(1.7)	6.2(.7)	6.1(.7)
Paralichthys lethostigma	.....	.....	.....	.....	24.4(2.7)
Trichiurus lepturus	7.2(.8)	17.0(1.9)	.....	.....	13.6(1.5)
Bairdiella chrysura	.....	.....	.....	.....	.....
Citharichthys spilopterus	.....	.....	.....	.....	.....
Polydactylus octonemus	.....	.....	.....	.....	.....
Anchoa hepsetus	.....	.....	.....	.....	.....
Others[1]	.....	.....	.....	.....	.....
Totals	192.6(21.6)	283.6(31.8)	483.1(54.2)	1573.7(176.4)	206.9(23.2)

1 Those fishes caught only once during the sampling period. (*Archosargus probatocephalus, Peprilus paru, Lagodon rhomboides, Vomer setapinnis, Stellifer lanceolatus, Cynoscion nebulosus, Menidia beryllina, Symphurus plagiusa, Chloroscombrus chrysurus, Sphoeroides, nephelus, and Orthopristis chrysopterus.*

Cynoscion arenarius Ginsburg—Sand Squeteague (Sand Trout)

Cynoscion arenarius was represented by 14 individuals and taken in only 29.4% of the drops. By weight they totaled 5.5 lbs (2.5 Kg) for the 17 drops. Though the size range varied greatly, from 30 to 415 mm, the average standard length was 170 mm. On several occasions both large and small sand trout (30 and 235 mm) were caught in the same drop.

Brevoortia gunteri Hildebrand—Bay Menhaden

This second species of menhaden numbered fourth on a lbs/acre basis but was taken in the open bay only on two occasions. Five individuals were taken in these two drops and the total catch was 4.7 lbs (2.1 Kg). All five fish were large, ranging between 212 and 256 mm and averaging 236.4 mm.

Leiostomus xanthurus Lacépède—Spot

If emphasis were being placed on fishes most often caught, then the spot and the croaker (*Micropogon undulatus*) would rank first. The spot was taken in 64.7% of the drops. By individuals it would rank fourth with 30. The weight figure for the 17 drops was 4.1 lbs (1.8 Kg). The size range was 50 to 170 mm and the average was 118.8

The data showed *L. xanthurus* to be an all-year resident of Corpus Christi Bay.

Galeichthus felis (Linnaeus)—Sea Catfish

Though its total catch of 2.4 lbs (1.1 Kg) is not great, the sea catfish would rank third in individuals with 53. It was present in 42.1% of the collections. The size range was between 38 and 203 mm and the average was 101.7.

The seasonal occurrence is much like that of *B. patronus* in that *G. felis* was not taken after September and then reappeared in March to remain common to the end of the summer. This agreed with Gunter (1945) who reported them largely absent from the bays in the winter but returning in the spring. Reid (1954) showed a peak abundance for them in May and that they were common throughout the summer at Cedar Keys, Florida. Though none was taken in the drop net in May, a large catch was made in June and they were indeed common through August.

Micropogon undulatus (Linnaeus)—Atlantic Croaker

As previously mentioned, the croaker and spot were the best represented of all the fishes in drop net catches. *Micropogon undulatus* occurred in 64.7% of the drops. The size range for the 26 individuals was 42 to 166 mm with an average of 111.6. Total catch for the 17 drops was 2.1 lbs (939.8 g).

Though the data indicated that the croaker was essentially an all year resident, the adults are known to migrate out of the bays in the fall (Pearson 1929) leaving only the sub-adult behind.

Paralichthys lethostigma Jordan & Gilbert—Southern Flounder

The southern flounder was taken on three occasions during the late winter and summer months and amounted to a total of 1.5 lbs (698.7 g) for the 17 drops. Only four were taken with a range of 113 to 268 mm and an average of 203 mm.

The presence of bottom-dwelling flatfishes in the helicopter drop net was considered indicative of sampling of benthic types. Other flatfishes taken that are mentionel later were *Citharichthys spilopterus* and *Symphurus plagiusa.*

Trichiurus lepturus (Linnaeus)—Atlantic Cutlassfish

The cutlassfish was taken four times and amounted to a total of 1.1 lbs (489.1 g). The seven individuals ranged from 390 to 472 mm with an average of 423.4.

Bairdiella chrysura (Lacèpéde)—Silver Perch

The silver perch was taken only twice. Four individuals were collected with a size range of 104 to 147 mm and an average of 123.2 mm. The total catch for the 17 drops was 0.4 lbs (174.2 g).

Annotated List of Remaining Fishes

The remaining fishes contributed only 5.9% of the total biomass. These species, minus those which were represented by a single specimen taken in a single drop, are given in the following list by decreasing order of total wet weight captured:

Citharichthys spilopterus Gunther was taken on three occasions between March and July. The three fish ranged from 55 to 75 mm.

Polydactylus octonemus (Girard) was taken only twice in the 17 drops. Reid (1955) found the threadfin to be one of the most common fiishes in open water (bays).

Anchoa hepsetus (Linnaeus) was taken three times and was represented by six individuals.

Archosargus probatocephalus (Walbaum) are more normally encountered around reefs, jetties, pilings, and wreckage than in the open bay (Gunter 1935 and 1941). These two large (275 and 320 mm) specimens were taken in one drop in March. It is quite possible that they were strays or migrants in the open bay. The large weight of these individuals gave them a remarkable 166.4 lbs/acre estimate which is probably too high for open waters.

Lagodon rhomboides (Linnaeus) was considered by Joseph and Yerger (1956) to rank very close to the striped mullet in species mass for Alligator Harbor, Florida, and Gunter (1945) found it not uncommon in bay trawl catches. It is odd that this species was taken only once (two individuals taken in March). Kilby (1955) noted the adeptness of this species in eluding capture and that it was most often found associated with marine grass habitats. Yet Springer and Woodburn (1960) found it abundant in Tampa Bay the year round and present at most of the stations sampled including flat sandy areas.

Symphurus plagiusa (Linnaeus) was taken once in March. The three individuals ranged from 84 to 122 mm. Simmons (1957) never found this species in water above 35 ppt. In this study it was taken in water above 46 ppt.

Menidia beryllina (Cope) was also expected to be more numerous but was taken only once in March. Five individuals were captured ranging from 72 to 83 mm.

Chloroscombrus chrysurus (Linnaeus) was captured only once in October. Ten speciments captured ranged from 28 to 36 mm.

Discussion

Biomass

The seasonal picture of biomass is presented in Table 4 where the average biomass for each season is shown. When the unusually large menhaden catch of August 5, 1963, is not considered, the numbers are remarkably constant for three of the four seasons. Though there are differences among the winter, spring, and summer seasons, the significance is doubtful. The figure for fall, on the other hand, is only half of that given for the other three and may be due to the large migrations of many of the marine species of the Gulf coast bays to the open Gulf to spawn. Copeland (1965) has shown that this could be the case.

Operational Problems Encountered

Maintenance of a Constant Area Sampled. As pointed out in the previous paper (Jones *et al.* 1963) there was a tendency for the net walls to constrict toward the center as the net was released from the frame. Therefore, some variability in net diameter must be expected when there is no rigid support for the sides of the cylinder.

Another source of error in estimating the area trapped by the net was a change in shape. A perfect circle of chain line on bottom was practically impossible. With good weather conditions and skillful maneuvering of the helicopter, near-perfect circles were not uncommon. Wind conditions of 20 kts. or greater were the greatest cause of collapse. Four of the attempted drops were discounted because of wind collapse of the windward face of the net. These collapses were obvious because the net either folded into a narrow ellipse with the chain lines less than three feet apart or landed in a hopelessly tangled mass. This situation is obviously best rectified by not dropping when wind speeds are at 20 kts, or above.

Escapement. The major area of escape was at the chain line during the pursing operation. One of the drops had to be discounted because of fouling of the bottom purse line with the deadman when an attempt was made to bring them up from the bottom separately. This was corrected by bringing the pursed net and the deadman up together. In addition the purse line was originally sewn into the net mesh 18 inches above the chain line. This was done to avoid scooping up large quantities of mud. It was assumed that all of the fishes would be driven up into the net above the purse line by the advancing chain line. Though this was the case with perhaps 90% of the fishes caught, some were

Table 4

Average Biomass per season in pounds per acre and grams per M^2 (in parentheses). Seasons are set up from Solstice to Equinox and vice versa

Season	Number of samples	Average biomass
Fall	2	107.8 (12.1)
Winter	5	225.6 (25.3)
Spring	2	217.1 (24.3)
Summer	8	421.7 [241.6][1] (47.1) (27.1)

[1] Biomass minus the unusually large *Brevoortia patronus* catch of August 5, 1963.

caught below the purse line. Fortunately, as the net was lifted from the bottom, the weight of the chain and folds of the net formed a second pocket from which no fishes were seen to escape. In spite of this latter observation, it is not altogether certain that some were not lost. Visibility on the bay bottom at recovery time with mud streaming from the net was limited. It was common practice after pursing for a diver to gather and tie off the bottom of the net skirt at the chain line before it was lifted clear of the bottom. As a solution it is suggested that the bottom purse line be lowered to a point about six inches above the chain line. The mud scooped up during the pursing operation was not found to be a problem as previously anticipated. The lowered purse line might serve to reduce escapement.

Replication of Drops. Although 24 drops were made, seven had to be discounted as a result of: winch power failures; collapsing nets, and other difficulties discussed in the above section. In addition, three major scheduling problems were encountered in this operation: bad weather (*i.e.*, high winds affecting the drop or high seas affecting the pursing operation); the fact that the military services (which donated the aircraft), though very generous with their time, often had other commitments to meet; and in several instances the frame was damaged and delays resulted while repairs were made. The frame was damaged several times during the helicopter pickup operations. It was accidentally released over land once. One frame was totally destroyed by Hurricane Carla.

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Strontium in Calcite: New Analyses[1]

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Abstract

Calcite specimens from the Brush Mineralogical Laboratory, Yale University, were analyzed for Sr and Ca and were considered a reference material to resolve a difference in published values for Sr-Ca ratios in freshwater mollusks. The new analyses showed the earlier published Sr concentrations were high by as much as an order of magnitude. These new data extend the lower range of Sr-Ca ratios in naturally occurring calcium carbonate minerals to 0.0224 Sr atoms per 1000 Ca atoms.

The purpose of this paper is to provide new analytical values for Sr and Ca concentrations in selected calcite samples from the Brush Mineralogical Laboratory of Yale University. Results of the calcite analyses and the analyses of two species of clams are compared with previously published results (Odum, 1957). The calcite samples are considered a reference material to resolve a discrepancy between Sr-Ca ratios in clam shells from the Clinch and Tennessee Rivers and other waters in eastern United States (Nelson, 1963). Odum (1957) analyzed an extensive series of calcareous materials for Ca and Sr and concluded that the Sr-Ca ratio in calcareous clam shells reflected the Sr-Ca ratio of their environment. The Clinch and Tennessee Rivers have a relatively high Sr-Ca ratio when compared with Sr-Ca ratios of other waters in eastern United States. According to Odum's hypothesis, a high Sr-Ca ratio should be expected in clam shells from this environment. However, when the results of the different analyses were compared, the Clinch and Tennessee River specimens had significantly lower Sr-Ca ratios than those reported by Odum (1957).

Possibilities that might account for the difference between the Sr-Ca ratios of the two suites of analyses are: analysis of different species, differences in the age and shell growth rate of clams analyzed, analytical errors, or sampling errors. Unfortunately, only with *Quadrula metanerva* was a species comparison possible between our analyses and Odum's. The Sr-Ca atom ratios in four Clinch-Tennessee River specimens were 0.183, 0.184, 0.185, and 0.188 (all times 10^{-3}) and in one analysis by Odum of a specimen from the Cumberland River near Nashville, Tennessee, the ratio was 0.46×10^{-3}. In this instance environmental factors may indeed have caused the difference in the Sr-Ca ratios. The analysis of 16 species including a total of 208 individuals from the Clinch and Tennessee Rivers showed the Sr concentration varied with the species, age of the individual and shell growth rate. However, the differences observed in Sr concentrations because of environmental or other factors were small when compared with those between the Sr-Ca ratios in *Quadrula metanerva*.

It is impossible to resolve differences that might have occurred from sampling errors but differences in analytical results could be resolved by analyzing samples of the same material. Since none of Odum's original mollusk specimens were available he suggested

[1] Research sponsored by the U.S. Atomic Energy Commission under contract with the Union Carbide Corporation.

(1962, Personal Communication) a comparison of Sr-Ca ratios in some of the same calcite specimens he analyzed. Strontium and Ca in these specimens were determined by flame spectrophotometry (Rains et al. 1962 and 1963).

The results of the new analyses of calcite and comparative analyses of two species of clams are listed in Table 1.

The analyses of Odum resulted in significantly higher Sr-Ca ratios than do the new analytical results. Only Sr-Ca ratios are available for comparison, hence, analytical errors for both Sr and Ca may be involved. In view of the fact that analytical techniques for Ca were better known than were the methods for Sr determinations, difficulties with Sr determinations are a more probable source of error. There is an order of magnitude difference between the ratios at the lowest Sr concentrations (Table 1, Egremont B 455 and Coppermine B 2260). Such a large difference would have been noticed in the analysis of calcareous materials for Ca, while these errors for a microconstituent such as Sr could go unnoticed. Moreover, the Ca concentration in fresh-water clam shells is constant (Nelson, 1963). Results from the analytical technique used for the determination of Sr in the new analyses were compared with results from NBS dolomite samples and the agreement was excellent (Rains et al. 1962). Accordingly, there is reasonable assurance the accuracy was good. In addition the replicate analyses of calcite samples and clam shells suggest excellent precision (Table 1).

The ratio of Odum's Sr-Ca ratios to the Sr-Ca ratios calculated from the new analytical results are plotted as a function of the Sr concentrations (Fig. 1). The plot shows that the difference between the two ratios decreases with increasing Sr concentrations. There is excellent agreement between results for *M. mercenaria* (=*Venus mercenaria*) which has a higher Sr concentration. *Mercenaria mercenaria* is expected to have a constant Sr-Ca ratio regardless of its collecting site, or other factors (Thompson

TABLE 1

Strontium and calcium analyses and a comparison of Sr-Ca atom ratios of calcite specimens and clam shells. Numbers with calcite specimens refer to specimens in Brush Mineralogical Laboratory, Yale University

Sample	mg/g		Sr-Ca atom ratios $\times 10^{-3}$		
	Ca[a]	Sr[a]	New analyses	Odum 1957	Ratio: Odum/new
Egremont, Cumberland, England, B 455	399, 395	0.021 0.018	0.0224	0.25	11.2
Coppermine, Lake Superior, B 2260[b]	358, 364	0.018, 0.018	0.0228	0.31	13.6
Fowler, N.Y., B 2272[c]	363, 368	0.108, 0.105	0.133	0.36	2.71
Joplin, Mo., B 191	380, 384	0.106, 0.104	0.126	0.44	3.49
Pargas, Finland, B 4192	397, 391	0.132, 0.133	0.154	0.48	3.12
Crestmore, Californa, B 3980	393, 393	0.542, 0.530	0.624	1.23	1.97
Quadrula metanerva (4 specimens)	[d]	0.162 ± 0.0009	0.185	0.46	2.49
Mercenaria mercenaria (10 specimens)	379.7 ± 4.57	1.931 ± 0.0257	2.326	2.387	1.03

[a] Duplicate analyses of calcite specimens. [b] SiO_2 present. [c] Black particles in specimen; spectrographic examination showed very strong Fe and a trace of silicon. [d] An average Ca concentration of 400.9 ± 1.38 mg/g ashed shell has been assumed (Nelson 1963). ± Standard error for clam specimens.

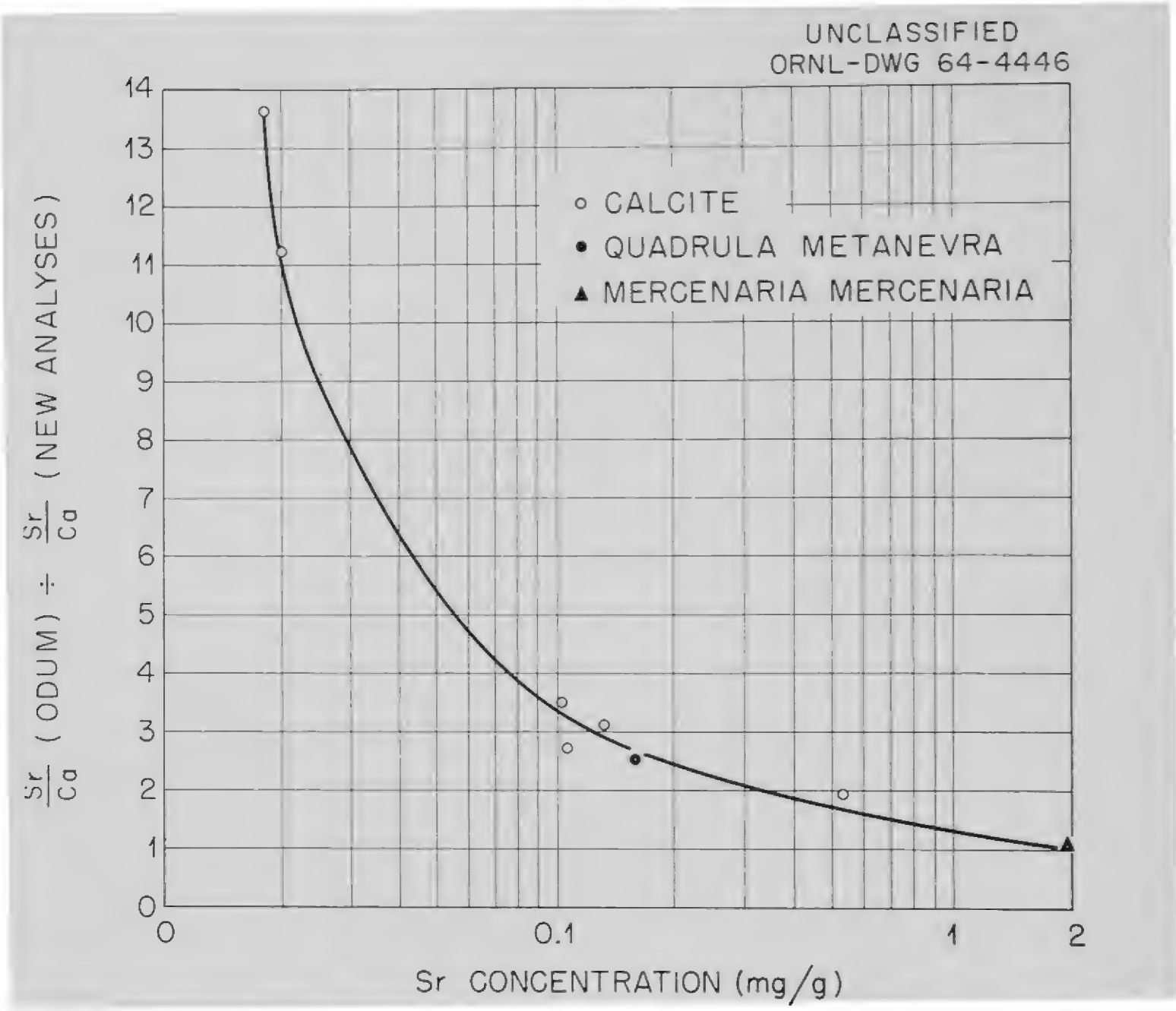

FIG. 1. Comparison of Sr-Ca ratios in calcite and clam shells as a function of the Sr concentration.

and Chow, 1955; Odum, 1957); therefore, the ratio in this marine species serves as another reference point for comparison of Sr analyses. In Odum's analyses accuracy increased with increasing Sr concentrations. The results of these new analyses of calcite are directly applicable to correct the erroneously high Sr-Ca ratios published previously (Odum, 1957). It is likely that the same correction may be applied to other calcareous materials having similar Sr concentrations.

Odum (1957) evaluated his analytical results from the standpoint of comparative Sr occlusion in calcite and aragonite. In his analyses of these minerals there was an overlap of their Sr-Ca ratios. Thus, these new analytical results do not in any manner change Odum's conclusions. However, these results show a greatly extended range in the Sr-Ca ratios of naturally occurring calcium carbonate minerals.

Acknowledgments

I should like to acknowledge discussion of this problem with Dr. H. T. Odum and his suggestion of analyzing the calcite samples. Dr. Horace Winchell, Brush Mineralogical Laboratory, Yale University, kindly provided the calcite samples. Mr. T. C. Rains, Analytical Chemistry Division, Oak Ridge National Laboratory, analyzed all samples.

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A Trawl Survey of the Shallow Gulf Fishes Near Port Aransas, Texas[1]

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Abstract

Between February and July, 1964, bi-monthly hauls were made in the 3–15 fathom zone of the Gulf off Port Aransas, Texas. Data presented for each of the 68 species captured include numbers, date and depth of capture, water temperature and size range taken. Also noted are size groups and ripe individuals. Where sufficient numbers of juveniles of a species were caught, its spawning season was estimated, based on growth data from other studies. For several species a migratory pattern was indicated. The data are compared with those of other studies of both surrounding habitats and other Gulf areas, and in most cases indicated the same migratory pattern and spawning season. Finally, the species for which no migratory pattern was indicated are grouped according to depth preference.

Introduction

The primary objective of the study was to follow the changes which occur in the fish fauna in the shallow Gulf of Mexico as the water temperature increased during the spring. A small-meshed trawl was used in an attempt to secure any life history data available through the capture of juveniles. The two other major studies which included the shallow Gulf (Gunter 1945; Hildebrand 1954) used the comercial otter trawl, which has considerably larger mesh.

The lowest water temperature occurred in the study area two weeks after trawling began. Trawling was continued into July, at which time it was felt the summer faunal pattern had been basically established.

Seasonal studies of fishes in the open Gulf of Mexico are rare in the literature. Habitats of the coastal area near Port Aransas, Texas, except for the area between the surf and 15 fathoms, have been studied extensively. Gunter's (1945) study was concentrated in Aransas and Copano Bays. Hildebrand (personal communication) stated that most of his 1954 paper reported on captures made in waters deeper than 15 fathoms. He was unable to sample areas regularly, being totally dependent on the shrimpers, who trawl wherever and whenever they feel it would be most profitable. McFarland (1963) was concerned with the fishes of the surf zone near Port Aransas. The data from the present study can be compared directly only with portions of Gunter's (1945) work on The Marine Fishes of Texas, his Louisiana (1938) study, Reid's (1954) study of the fishes of Cedar Key, Florida and Springer and Woodburn's (1960) study of the Tampa Bay, Florida area. Though Hildebrand's (1954) sampling of the brown shrimp grounds was sporadic, his observations regarding the seasonality of certain species from the Texas Grounds form an important basis for comparison, as do those of McFarland (1963).

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The Study Area and Its Hydrography

Six stations were sampled at regular bi-monthly intervals; five were in the shallow Gulf of Mexico, and one was in Aransas Bay (Fig. 1). The five Gulf Stations are numbered 3, 6, 9, 12 and 15 corresponding to their respective depths in fathoms. They were located on a course of approximately 112° magnetic beginning two miles north of the Port Aransas jetties. By beginning this far north of the jetties the study area was well out of the area in which the Army Corps of Engineers dredge was dumping material cleaned out of the channel.

The Aransas Bay Station was located just out of the Lydia Ann Channel to the east of the Intracoastal Canal between markers 79 and 83. The depth of the bay here is about one and one-half fathoms. The bay station was used only as an attempt to detect any local migration into or out of the bay from the Gulf.

Gunter (1945) described the physiography of the area in detail except for the shallow Gulf. Therefore, grab samples of the sediment were taken at each station in the Gulf on February 21. Dr. E. William Behrens, geologist at the Institute of Marine Science, described the bottom samples as follows: 3 fathoms—Hard sand (this bottom type is found all the way into the beach); 6 fathoms—Sandy mud, with sand layers; 9 fathoms —Very sandy mud with some shell fragments; 12 fathoms—Pure mud, no shell; 15 fathoms—Same as 12.

Jones, Copeland and Hoese (1965) have studied the hydrography of the area and reported the results in detail. Surface and bottom salinities and temperatures were determined during the corse of my study for comparative purposes. Bottom salinities and temperatures are presented in Table 1.

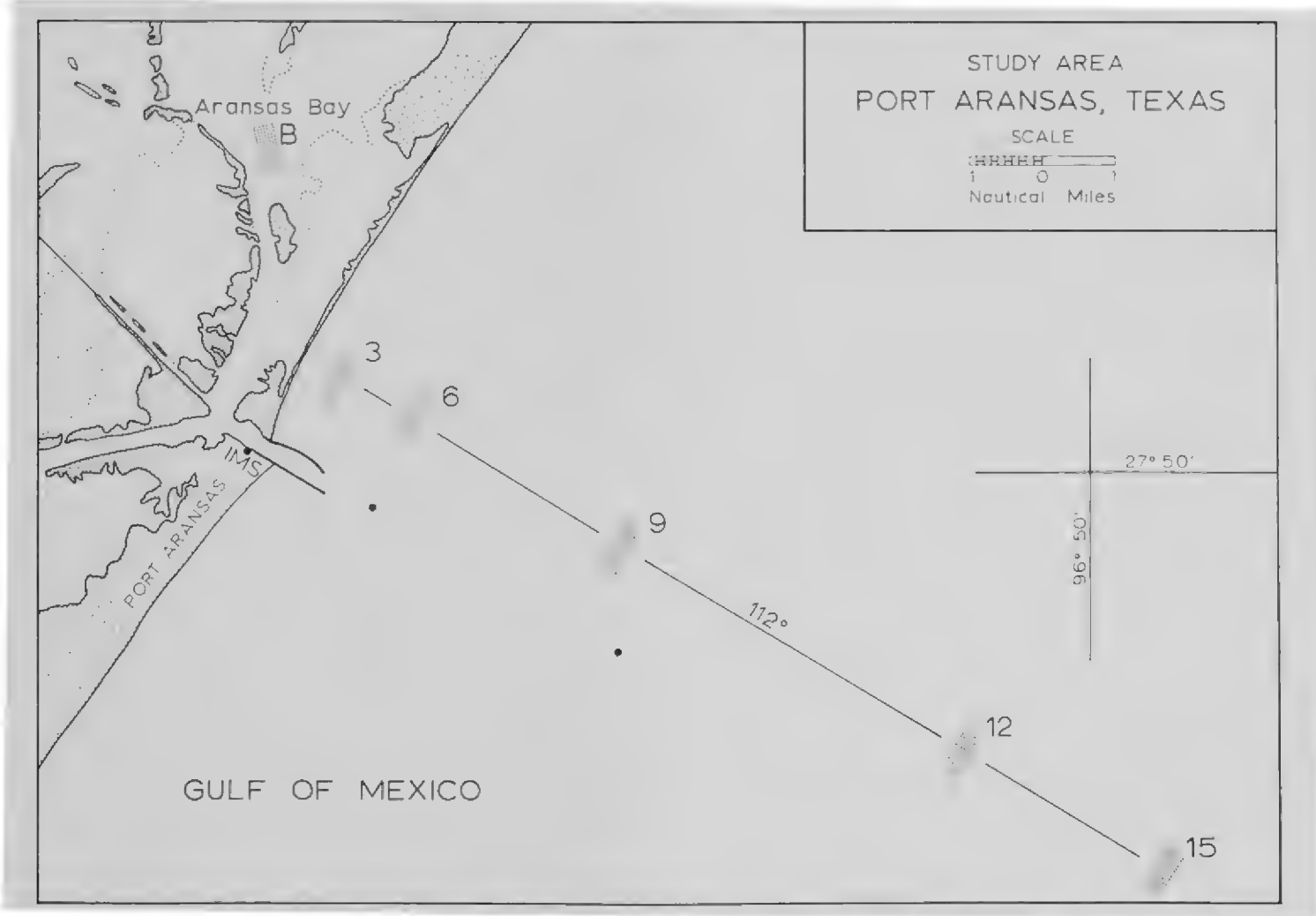

FIG. 1. Diagram of the study area. Stippled rectangles indicate sampling areas with the number indicating station depth in fathoms.

TABLE 1

Bottom salinity and temperature

Station no.	3	6	9	12	15
Feb. 19–20					
Salinity (ppt.)	35.1	35.2	35.2	35.1	35.6
Temperature (C)	14.7	14.6	13.8	13.7	14.7
Time of haul	0945	1030	1000	1042	1150
Mar. 2–4					
Salinity (ppt.)	34.9	35.0	35.2	35.6	36.0
Temperature (C)	13.2	12.8	12.9	13.6	14.4
Time of haul	1013	1047	1131	1226	1328
Mar. 19					
Salinity (ppt.)	33.6	33.5	34.3	34.5	35.2
Temperature (C)	17.0	16.5	15.6	15.2	15.8
Time of haul	0747	0820	0947	1039	1137
Apr. 1–3					
Salinity (ppt.)	31.6	31.8	32.1	34.7	35.5
Temperature (C)	18.3	17.3	16.4	16.4	17.0
Time of haul	1420	0907	0957	1051	1203
Apr. 16					
Salinity (ppt.)	27.6	27.3	31.9	33.7	35.2
Temperature (C)	20.7	19.8	18.8	18.4	18.1
Time of haul	0738	0815	0913	1021	1128
Apr. 28–May 2					
Salinity (ppt.)	26.2	31.2	31.2	34.1	35.4
Temperature (C)	23.4	22.8	23.6	21.5	20.9
Time of haul	0851	0904	0947	1041	1142
May 16					
Salinity (ppt.)	26.4	26.4	26.8	35.6	36.0
Temperature (C)	25.1	25.2	25.0	22.8	22.8
Time of haul	0732	0806	0855	1001	1104
June 2					
Salinity (ppt.)	31.6	32.0	33.2	35.2	35.6
Temperature (C)	25.5	25.2	25.2	24.6	24.3
Time of haul	0840	0911	1002	1101	1211
June 22–23					
Salinity (ppt.)	35.6	36.0	34.2	35.6	35.6
Temperature (C)	27.5	27.8	26.5	25.6	25.7
Time of haul	0940	1018	0919	1016	1123

Methods

The trawl measured 22 feet from the cork line to the cod end including the four foot bag, and 19 feet wide at the mouth. It was three feet deep from cork line to lead line while towed, and was equipped with a "tickler chain" between the 2 × 5 foot weighted, plywood otter boards. The entire trawl, except the chafing gear, was constructed of ¾ inch stretched (⅜ inch bar) mesh nylon netting. The openings in the netting were ¼ the area of those of the trawl used by Gunter (1945) and were similarly smaller than most commercial otter trawls such as those used by Hildebrand (1954) to collect his samples.

Hauls were made at five stations in the shallow Gulf and one station in Aransas Bay twice each month between February 19 and the middle of July (Fig. 1). Preliminary trawling indicated that 15 minutes of trawling at approximately two knots, a distance of about ½ mile, caught suitable quantities of fish and did not overburden the small trawl with weight. The time of day of the hauls was quite consistent, beginning around 0800 hours and ending in the early afternoon (Table 1). Hauls in the Gulf were made by following the bottom contour at the desired depth on the fathometer.

Surface and bottom salinities and temperatures were taken at the time of each trawl. Salinities were determined by the Mohr silver nitrate method (Barnes, 1959), and with an American Optical Company Goldberg Refractometer (Behrens, 1965). Water temperatures were taken with a mercury-in-glass thermometer. Air temperatures, along with estimates of water color, wind and sea state were recorded but no correlation with fish data could be found.

The fish were placed in formalin immediately following capture and were identified, counted, measured and weighed in the lab. All measurements, unless otherwise noted, are to the nearest millimeter of total length (from the tip of the snout against the measuring board to the tip of the longest caudal ray). Speed of measurement and the similar use of total length by Gunter (1945) determined the choice of total instead of fork or standard length measurement.

Because of the small samples of most species obtained, presentation of the data obtained at the individual stations would be so influenced by sample size that patterns would be obscured. Therefore I have grouped the data from all stations for purposes of calculations such as relative abundance and average size. However, where certain of the more abundant species were clearly confined to a certain part of the study area or moved within the area, such patterns are discussed in the Systematic Account of the individual species.

Results

Day-Night Trawling

An attempt was made to estimate the relative susceptibility of fish to capture during daylight and dark. On April 11, hauls were made at the 6-fathom station at 1800 hours and again after dark at 2130 hours, and the data are presented in Table 2. The water was relatively clear, with the bottom salinity 29.4 ppt and the bottom temperature 19.3 C.

Of the 12 species taken only at night, an increase in susceptibility to capture is postulated for *Otophidium welshi, Brotula barbata, Symphurus plagiusa, Etropus crossotus, Anclyopsetta quadrocellata* and *Achirus lineatus,* based on a probable increase in activity at night. The capture of six other species only at night was probably due to chance. All 12 species were taken during the day on other dates.

Four species were taken in the daylight haul only. *Trichiurus lepturus* is known to feed at the surface at night. The capture of *Peprilus paru, Brevoortia patronus* and *Anchoa* sp. in the daytime haul only, was probably due to chance.

Among the changes in relative numbers of species taken in both hauls those of *Micropogon undulatus, Stellifer lanceolatus* and *Cynoscion nothus* were over twice their lowest numbers. It would be difficult to attribute these changes to chance alone. Whatever the cause, these data alone suggest that further investigation of diurnal variation in activity of fishes is needed.

Systematic Account

All fishes collected in the trawl survey are listed in Table 3, along with the date of their appearance and the number collected. These fishes are discussed in the following pages in the order that Hoese (1958) listed them.

TABLE 2

Results of day and night trawls, April 11, 1964

	Day	Night
Micropogon undulatus	45	108
Stellifer lanceolatus	22	104
Cynoscion nothus	69	10
Cynoscion arenarius	5	2
Lagodon rhomboides	1	3
Poronotus triacanthus	8	1
Polydactylus octonemus	1	8
Urophycis floridanus	1	4
Peprilus paru	1	..
Anchoa sp.	19	..
Trichiurus lepturus	26	..
Brevoortia patronus	1	..
Leiostomus xanthurus	..	1
Menticirrhus litoralis	..	1
Larimus fasciatus	..	5
Orthopristis chrysopterus	..	1
Chaetodipterus faber	..	4
Prionotus tribulus	..	2
Otophidium welshi	..	4
Brotula barbata	..	1
Symphurus plagiusa	..	2
Etropus crossotus	..	1
Anclyopsetta quadrocellata	..	1
Achirus lineatus	..	1
TOTALS	199	264

TABLE 3

Distribution of specimens in Gulf Trawl collections in their general order of appearance

Species \ Date	Feb. 19–20	Mar. 2	Mar. 19	Apr. 1	Apr. 16	Apr. 28 May 2	May 16	June 2	June 22–23	Total
Cynoscion nothus	145	228	218	117	92	537	553	213	139	2242
Stellifer lanceolatus	112	55	26	81	....	33	290	10	9	616
Micropogon undulatus	96	1	12	11	3	3	1114	706	426	2372
Trichiurus lepturus	79	35	21	14	29	15	49	102	50	394
Menticirrhus americanus	38	11	8	5	1	....	....	5	..	68
Cynoscion arenarius	36	5	21	5	1	....	9	87	222	386
Menticirrhus litoralis	2	....	12	2	....	....	....	....	....	16
Larimus fasciatus	11	6	6	1	....	....	5	12	2	43
Leiostomus xanthurus	1	....	2	1	....	....	20	69	99	192
Orthopristis chrysopterus	6	....	2	....	1	....	....	1	....	10
Galeichthys felis	61	22	17	2	....	1	1	2	....	106
Synodus foetens	9	14	23	2	2	58	12	10	6	136
Symphurus plagiusa	12	32	10	17	5	1	1	10	1	89
Peprilus paru	1	....	1	....	....	....	....	7	4	13
Poronotus triachanthus	7	9	31	16	45	66	13	12	7	206
Urophycis floridanus	15	2	9	6	1	2	....	....	....	35
Paralichthys albigutta	1	1	....	....	....	1	....	....	....	3
Etropus crossotus	4	6	4	1	1	....	....	....	....	16
Anclyopsetta quadrocellata	3	2	3	1	2	2	....	..	..	13
Syacium gunteri	61	71	20	19	7	19	8	13	12	230
Brevoortia patronus	1	....	....	1	....	....	....	1	....	3
Lagodon rhomboides	6	....	....	2	5	....	....	16	1	30
Centropristis philadelphicus	3	2	8	2	1	1	....	5	3	25
Diplectrum arcuarium	1	1	1	....	2	1	1	3	....	10
Sphoeroides nephelus	10	2	....	1	....	....	....	..	2	15
Prionotus tribulus	8	1	3	....	1	1	....	2	....	16

TABLE 3—(Continued from previous page)

Distribution of specimens in Gulf trawl collections in their general order of appearance

Species \ Date	Feb. 19–20	Mar. 2	Mar. 19	Apr. 1	Apr. 16	Apr. 28 May 2	May 16	June 2	June 22–23	Total
Porichthys porosissimus	2	1	....	....	....	3	1	....	....	7
Anchoa sp.	151	14	212	81	107	12	17	354	516	1464
Astroscopus y-graecum	2	1	....	1	....	....	....	....	....	4
Dasyatis sabina	6	2	....	....	....	....	....	....	....	8
Otophidium welshi	1	....	....	....	....	....	....	..	....	1
Bollmannia communis	1	1	8	....	4	3	....	5	....	22
Antennarius radiosus	....	18	71	3	17	2	....	....	....	111
Chactodipterus faber	....	1	....	4	....	....	....	....	....	5
Chilomycterus schoepfi	. .	1	1	....	....	....	....	1	....	3
Raja texana	..	1	....	....	....	....	....	....	....	1
Monacanthus hispidus	....	1	....	....	..	....	....	....	....	1
Achirus lineatus	....	1	1	....	....	....	....	....	....	2
Lepophid'um brevibarbe	....	1	1	....	....	....	....	....	....	2
Lonchopisthus lindneri	....	1	..	..	....	....	....	....	....	1
Bagre marinus	....	....	2	....	....	....	2	. ..	4	8
Citharichthys spilopterus	....	....	1	3	....	2	....	7	2	15
Urophycis cirratus	....	....	18	4	6	2	....	....	....	30
Gymnothorax nigromarginatus	....	....	1	....	1	1	....	1	....	4
Brotula barbata	....	....	2	....	....	....	....	....	....	2
Ogcocephalus sp.	....	....	2	....	1	1	....	....	....	4
Halieutichthys aculeatus	....	. ..	1	....	....	....	....	. .	....	1
Chaetodon ocellatus	....	....	....	1	....	....	....	....	....	1
Polydactylus octonemus	....	....	....	3	39	28	121	23	13	227
Etrumeus teres	....	....	....	....	6	....	....	....	....	6
Gobinonellus gracillimus	....	. .	....	..	1	5	....	6	....	12
Chloroscombrus chrysurus	....	....	....	....	....	11	9	....	..	20
Saurida brasiliensis	....	....	....	....	....	7	....	. .	....	7
Prionotus pectoralis	....	....	....	....	....	1	....	....	....	1
Balistes capriscus	....	....	....	....	....	1	....	....	....	1
Stenotomus caprinus	....	....	....	....	....	1	....	....	....	1
Vomer setapinnis	....	....	....	....	....	....	3	19	28	50
Lagocephalus laevigatus	....	....	....	....	....	....	1	3	3	7
Bairdiella chrysura	....	....	....	....	....	....	....	1	....	1
Trachurus lathami	....	....	..	....	..	..	....	2	7	9
Conodon nobilis	....	....	....	....	....	....	....	....	1	1
TOTALS	892	550	779	407	381	821	2230	1708	1557	9325

Dasyatis sabina (LeSueur)—Atlantic Stingray

Eight specimens taken in the Gulf during my study were collected at three and six fathoms on February 19 and March 2. The temperature range was 12.8–14.7 C. All were between 135 and 227 mm (disc length). Gunter (1945) found this stingray to be most abundant in the Gulf in winter and spring. He stated that it left the bays in the winter; however, the only one I obtained from Aransas Bay was a 302 mm female collected February 20, when the water temperature was 14.8 C.

Raja texana Chandler—Roundel Skate

One 235 mm (disc length) specimen was taken at 12 fathoms on March 2. The temperature was 13.6 C. Gunter (1945) took four specimens from the Gulf between January and May. Hildebrand (1954) found this ray to be present in the shallow Gulf throughout the year.

Brevoortia patronus Goode—Largescale Menhaden

Three small specimens were taken in the Gulf at 3 and 6 fathoms on February 19, April 1, and June 2. Their sizes were 55, 190 and 68 mm, respectively, and the temperatures were 14.7, 17.3, and 25.5 C. Suttkus (1956) took the majority of juveniles, between 55 and 70 mm, in May in Louisiana. Roughly the same was observed by Springer and Woodburn (1960). Neither took them in this size range earlier than April. Gunter (1945) states that spawning occurs from mid-winter to spring. The 55 mm specimen taken in February obviously does not support this conclusion. Rather it is indicative of the conclusion drawn by Suttkus (1956) that they spawn as early as October in Louisiana.

Etrumeus teres (DeKay)—Round Herring

On April 16, six specimens between 47 and 66 mm were taken in 15 fathoms. The water temperature was 18.1 C. Other than specimens from Oregon collections at 23 and 29 fathoms (Springer and Bullis, 1956) this, to my knowledge, is the only record of this species from Texas. According to Whitehead (1963) this species may reach 260 mm so it is possible that these specimens are products of a winter spawn.

Anchoa sp.—Anchovies

One thousand seven hundred and fifty-four anchovies were caught in the Gulf between February 19 and June 22. The temperature range was from 12.8 C to 27.6 C. Most of the specimens were taken from depths of 3 and 6 fathoms. Unfortunately, it was the author's belief when the study was begun, the two common species, *Anchoa mitchilli diaphana* and *Anchoa h. hepsetus* were separable only by fin ray counts and, therefore, would require too much time to distinguish. Hence, the data in Table 3 are for all species of *Anchoa*. However, the 12 largest specimens taken between May 2 and June 2 were all identified as *Anchoa h. hepsetus*. With the assistance of Mr. Hinton D. Hoese, the 970 specimens taken on June 2 and 22 were identified to species. Of these only 36 were *hepsetus*, the rest were *mitchilli*. None of the 970 were *Anchoa lyolepis*. However, one 78 mm *A. lyolepis* appeared in the trawl at 15 fathoms on July 13. Since Gunter (1945) took only six of this species in minnow seines, it is improbable that any other of my specimens were *A. lyolepis*.

The above indicates a differential distribution for *A. mitchilli* and *A. hepsetus* in my study area, but the omission of critical data prevented ascertaining the pattern.

Two of the larger *A. h. hepsetus* taken April 11 were ripe. Gunter (1945) took ripe females in April and May, indicating at least a spring spawning season. Of the *A. h. hepsetus* identified, there were two distinct size groups; one from 37 to 77 mm and, the 12 taken in May and June, from 119 to 136 mm.

The *A. mitchilli diaphana* which were identified seemed also to belong to two distinct size classes. Eleven taken on June 22 in a ¼-inch square mesh liner were from 30 to 37 mm. All others were from 46 to 75 mm. No obvious modes were detected in this group. The wide spread range of sizes is consistent with the long breeding season reported by Gunter (1945) as probably extending between spring and fall. According to the growth rate described by Hildebrand and Cable (1930) these two groups could have been spawned during spring and fall, respectively.

An explanation for the drastic fluctuation in their abundance in the trawl collections probably lies in the fact that both species travel in schools which may have accidentally encountered the net, resulting in the large catches shown in Table 3.

Saurida brasiliensis Norman—Largescale lizardfish

Seven specimens of this rare lizardfish were taken May 2 at 12 and 15 fathoms. The bottom temperatures were 21.5 and 20.9 C respectively. Six of the specimens were between 92 and 125 mm. The other (approximately 70 mm) had been recently disgorged by its predator. Of the studies I have available for comparison, only Hildebrand (1954) took this species, mainly from water deeper than 15 fathoms. According to Hoese (1958) it has been recorded on four occasions from the *Oregon* collection in 15 to 29 fathoms by Springer and Bullis (1956). Apparently this is a deeper water species which explains its single occurrence in my study area.

On July 13 two small (55 and 61 mm) specimens were taken at 15 fathoms along with another (140 mm) specimen. The two small specimens are the first records indicating this species' spawning which would have been in the winter or spring (depending on the growth rate) for these specimens.

Synodus foetens (Linnaeus)—Inshore lizardfish

One hundred thirty-six lizardfish were taken in the Gulf. They were present throughout the study as shown in Table 3. Only one specimen, measuring 173 mm, was taken at 6 fathoms and only eleven at 9 fathoms. The peak on May 2 can perhaps be explained by the occurence of blue water unusually close to shore which may have brought more fish into the study area on that date. McFarland (1963) did not take this species in the surf zone. Hildebrand (1954), working mainly in water deeper than 15 fathoms, took 9,800 lizardfish, of which he estimated 75% were *S. foetens*. These data established this species as occurring mainly in water deeper than 12 fathoms. Gunter (1945) took this species from the Gulf only from July to October, undoubtedly because his deepest station was 10 fathoms. The eleven fish were taken after April 16, which may indicate an inshore movement with increasing water temperature. Gunter (1945) took them in the bays between March and November.

The specimens I took ranged from 93 to 359 mm. If Gunter's (1945) 61 and 73 mm specimens he took in July are products of a spring spawning season as he says, a 93 mm specimen I took on March 19 is too large to be young-of-the-year and possibly may have been spawned the preceding summer or fall. Springer and Woodburn (1960) took several 33 to 35 mm specimens in November and December which also indicated a fall spawning season.

Bagre marinus (Mitchill)—Gafftopsail Catfish

Eight gafftopsails were caught in the Gulf between March 19 and June 22. Two were caught at 6 fathoms on each of these dates. Two were also caught at 6 fathoms on May 16, and at 3 fathoms on June 22. The last two measured 333 and 299 mm, the others between 141 and 194 mm. The temperature range was 16.4–27.8 C. None were in breeding condition, though the eggs or young may have been spit out when captured. The spawning season in Texas is probably in May (Gunter, 1945).

Galeichthys felis (Linnaeus)—Sea Catfish

One hundred six specimens were taken in trawls in the Gulf. All except one were taken at 3 or 6 fathoms. The bottom temperature range was 13.2–25.5 C. Sea catfish were caught each month with their greatest abundance and relative abundance in the trawls (8.2 per cent of the catch) occurring on February 19 and dropping off rapidly as the water became warmer.

The peak of 61 specimens taken February 19 in 3 fathoms occurred at approximately the same time of year as an exceptional number found by McFarland (1963) in the surf zone, which he described as a breeding aggregation. Hildebrand (1954) stated that this species is not common offshore during the winter months. The size range encountered was from 73 to 213 mm. My data shed no light on the breeding season which is well known due to the habit of oral gestation (Gunter, 1945; Reid, 1954; Springer and Woodburn, 1960). The decreasing abundance in spring in the Gulf supports Gunter's (1945) viewpoint that they move into the bays then. It is possible that this species moves into the shallow Gulf only to winter.

Gymnothorax nigromarginatus (Girard)—Blackedge Moray

Four specimens were taken, one each month from March to June. All were between 254 and 336 mm. The temperature range was 15.8–24.6 C. The specimen taken in June came from 12 fathoms, the others from 15 fathoms. Hildebrand (1954) took 24 in the Texas shrimp grounds in depths between 12 and 34 fathoms, but gave no seasonal information. None were taken during any of the other Gulf investigations reviewed, indicating that this species prefers deeper water.

Urophycis floridanus (Bean and Dresel)—Southern Hake

Thirty-five specimens of *U. floridanus* were taken from the Gulf and fifteen from Aransas Bay (Table 3). They were caught mainly at the three inshore stations in February and March, and had left the study area by the middle of May. The greater percentage of them were taken in deeper water as the season progressed.

Hildebrand (1954) stated his data indicated they spend the summer in water deeper than 18 fathoms. The Florida studies show this species leaves shallow water as the temperature increases. The temperature range was 12.8–23.6 C.

Thirty-four Gulf specimens had a size range from 51 to 148 mm. One 292 mm specimen was caught on February 19 at 9 fathoms.

Hildebrand and Cable (1938) stated that specimens 50–100 mm long were approximately two months old. My specimens in this size range were taken in February and March, indicating a winter spawning season here similar to that in Beaufort.

Gunter (1945) took over twice as many specimens in Aransas and Copano Bays as in the shallow Gulf, mainly between February and April, indicating this species is more numerous in this area than the present study shows.

Urophycis cirratus (Goode and Bean)—Gulf Hake

This species apparently was not taken by Gunter (1945) or Hildebrand (1954), in their studies of this area. As it is commonly believed that *U. floridanus* is the only

inshore species, it is possible that some specimens have been mis-identified as *U. floridanus*. Hoese's (1958) check list has records of this species only from 100 fathoms.

Nearly as many specimens (30) were taken in this study between March 19 and May 2 as *U. floridanus*, indicating a similar offshore movement with increasing water temperature. The temperature range was 15.2–20.9 C.

This species apparently did not enter the bays as did *U. floridanus*, being taken only at 12 and 15 fathoms which may account for their absence in Gunter's work. It would seem, however, that they should have been encountered by Hildebrand.

Twenty-nine specimens were between 60 and 129 mm. One slightly larger (148 mm) specimen was obtained on April 16. If one assumes a similar growth rate for *U. cirratus* as for *floridanus* the similar sizes of the small specimens of both species taken in March would indicate a similar winter spawning season.

Diplectrum arcuarium Ginsburg—Sandfish

All but two of the 15 specimens taken were captured at 15 fathoms. They were present in the trawls every month. Ten were between 102 and 138 mm, measured to the tips of the longest lower caudal rays. The upper one is produced but was often broken. On July 13 five specimens from 19 to 60 mm were taken at 15 fathoms. Hildebrand (1954) took smaller (24 to 40 mm) specimens in July, which may indicate a winter and spring spawning season. In all he counted 4,350 from the Texas shrimp grounds and believed them to be most abundant between 15 and 30 fathoms. My data support his contention. This species was not taken by Gunter (1945), McFarland (1963) nor in any of the Florida studies. The temperature range was 14.4–24.6 C.

Centropristes philadelphicus (Linnaeus)—Rock Sea Bass

Twenty-five specimens were taken throughout the study, of which all but six were taken at 12 and 15 fathoms. Three each were taken at 6 and 9 fathoms. None were taken from 3 fathoms and McFarland (1963) did not take this species from the surf zone. Gunter (1945) took only seven specimens, from 84 to 127 mm, from the Gulf in 60–70 feet of water. Hildebrand (1954) called it the common sea bass of the brown shrimp grounds which indicates this species is common mainly in water deeper than 18 fathoms.

The size range was 43 to 171 mm. There was an indication of at least two age classes. All specimens taken were from 91 to 141 mm until April 16, when a 43 mm specimen was taken. In May two specimens, 124 and 171 mm, were taken while eight, from 59 to 86 mm, were caught in June. Presumably the 43 mm specimen taken in April belonged to this latter group. Hildebrand (1954) also took small (68 mm) specimens in May. Miller (1959) states this species probably spawn in May and June; however, it would seem that the smaller specimens I took were spawned much earlier, perhaps in the winter.

Chloroscombrus chrysurus (Linnaeus)—Bumper

Twenty bumpers were taken during this study, all in May. Of these, all but two (one each at 9 and 12 fathoms on May 2) were taken in 3 or 6 fathoms of water. The temperature range was 21.5–25.2 C. All were between 140 and 173 mm long. This species

appears in the surf zone in great numbers in May and is essentially absent in the fall and winter (McFarland, 1963). Gunter (1945) however, took them from the Gulf in trawls as late as September. Hildebrand (1954) stated that this species moves into the shallow (less than 12 fathoms) water during the summer months. He took them during March in 37 fathoms. The sudden appearance of this species in my trawls in May, and its absence later, corroborates the above ideas concerning its seasonal behavior. Both Reid (1954) and Springer and Woodburn (1960) found its greatest inshore abundance in September and October in Florida, in contrast to Gunter (1945), who found them to be most abundant in Aransas Bay and the Gulf in August. Gunter (1945) took a ripe female and three ripe males from the Gulf in August.

Vomer setapinnis (Mitchill)—Atlantic Moonfish

Fifty moonfish were taken, all on or after May 16. The temperature range was 22.8–27.8 C. Only two were taken at 15 fathoms, so this species obviously moves rapidly to the inshore waters.

They could be divided into two size groups, from 45–84 mm (46 specimens), and four from 123–157 mm. The three taken on May 16 fell into this latter group. Only four of the smaller fish occurred in water deeper than 3 fathoms.

Gunter (1945) took this species, mainly from the Gulf, every month except January and February, with August the most productive month. Hildebrand (1954) noted the greatest abundance during the summer months in less than 15 fathoms. None were taken by Reid (1954) nor Springer and Woodburn (1960) in Florida. No life history data could be found.

Trachurus lathami Nichols—Rough Scad

Nine specimens were taken in June, all at 12 and 15 fathoms. Those taken on June 2 were 73 and 85 mm long, while the seven taken on June 22 were between 117 and 137 mm. The temperature range was 24.3–25.7 C. Gunter (1945) took 29 specimens in one haul in July for his only records of their occurrence in the Gulf, and described it as occurring sporadically during the summer. He took none in the bays. The fact that McFarland (1963) did not take this species in the surf zone, and the above data, indicate it is a deeper water species. Hildebrand (1954) took 410 from the Texas coast, and stated it is common here only during the summer months, which agrees with my data. Neither Springer and Woodburn (1960) nor Reid (1954) took this species from Florida.

Orthopristis chrysopterus (Linnaeus)—Pigfish

Only ten pigfish were taken in the Gulf during the February through July study period, in every month except May. All were taken in 9 fathoms of water or less. They were numerous in the trawls in Arkansas Bay every month except February, when I took six of the ten in the Gulf. Gunter (1945) took the largest number from the Gulf in November and January which also indicates this species may move into the shallow Gulf from the bays in the winter and return in the spring. Hildebrand (1954) found "a few specimens" in 3–15 fathoms in October for his only Texas record, and stated it is much more common in the bay grass flats. Reid (1954) found this to be true at Cedar Key, Florida. Their temperature range was 13.8–25.2 C.

Of the ten, nine were from 116 to 140 mm. A 60 mm specimen was taken on June 2, which probably belonged to another age class. Gunter (1945) took ten ripe females in March from Lydia Ann Channel. The 60 mm specimen mentioned above occurred at about the same time of year as similar size juveniles were taken by Hildebrand and Bable (1930) near Beaufort. This would seem to indicate similar spawning seasons for both localities, that is, between March and June. Juveniles taken by Springer and Woodburn (1960), and Reid (1954), indicate a similar season in Florida.

Bairdiella chrysura (Lacépède)—Silver Perch

One specimen was taken in the Gulf at three fathoms on June 2. Six were taken from March 3 to June 2 in Aransas Bay. The bottom temperature at three fathoms on June 2 was 25.5 C. All seven were from 110 to 172 mm in length. Gunter (1945) did not take this species in the Gulf except in November and January, but he did not trawl in water this shallow. McFarland (1963) found this species in the surf zone from January through April so my specimen extends its records from the Gulf from November to June. Hildebrand (1954) did not take this species so the data indicate it remains inshore.

Of the seven fish, one ripe female was taken on April 1 in the bay, at a temperature of 19.4 C. The 173 mm female taken in the Gulf had mature ovaries. Reid (1954) took a ripe female near Cedar Key in June. Springer and Woodburn (1960) took a nearly ripe female in March from Tampa Bay. Gunter (1945) took a ripe female from Copano Bay on April 20. Hildebrand and Cable (1930) place the spawning season from April to July in the vicinity of Beaufort, which is consistent with the data taken from the Gulf.

Cynoscion arenarius Ginsburg—Sand Seatrout

Three hundred eighty-six sand seatrout were taken in the Gulf throughout the study and from the lowest (12.8 C) to the highest (27.8 C) water temperatures encountered. Eighty percent of these were taken at 6 fathoms, not more inshore as Ginsburg (1931) suggests. The remainder were rather evenly distributed in the catches from the other depths. Similarly, the absence of this species from my bay collections does not support Gunter's (1945) hypothesis that this is a bay inhabitant. The monthly occurrence is shown in Table 3. The time of greatest relative abundance (21.3 per cent of the catch) is coincidental with the greatest number on June 22.

The size range encountered was 35 to 236 mm. Until May 16 all but one 194 mm specimen appeared to belong to a single size group from 72 to 136 mm in length. On that date and subsequently a group of smaller (35 to 56 mm) fish were found in the catch. It is possible that these represented the first young-of-the-year. Gunter (1945) noted a similar (23 to 38 mm) group in April.

These young-of-the-year tended to merge in size with the older fish, however in June very small fish were still found. Six large specimens from 168 to 236 mm were caught that possibly were much older.

No ripe specimens were taken though the juveniles mentioned earlier indicated a spring spawn. My data corroborates the extended (spring and fall) breeding season suggested by Gunter's (1945) data. The reports of juveniles taken from Florida by Reid (1954) and Springer and Woodburn (1960) also concur.

Cynoscion nothus (Holbrook)—Silver Seatrout

This seatrout was present in relatively high numbers throughout the temperature range encountered (12.8–27.8 C). The lowest relative abundance was on February 19 when it constituted 19.5 per cent of the catch, and the highest on May 2 (66.3 per cent). In all, 2,242 individuals were taken between February 19 and June 22. It was taken at every station although mainly from 6 to 12 fathoms. Ginsburg (1931) states this is an offshore species while *C. arenarius* is more common in the bays and Gulf inshore waters with *nothus* becoming more common some distance offshore. My data do not concur. *C. arenarius* was never taken in greater numbers than *nothus* at 3 fathoms; only once, on June 22, was it more common than *nothus* at 6 fathoms and was never taken in greater numbers than *nothus* at any of the deeper stations. The total number of *nothus* taken is nearly 6 times that of *arenarius*. McFarland (1963) took neither of the species in the surf zone.

The size range encountered was 52 to 194 mm. Most of the individuals taken February 19 were rather evenly distributed between 52 and 122 mm with four others between 132 and 150 mm. In March there were also four specimens in this larger size range. In April and May the two groups previously noted could not be separated, and by June all fish taken were between 106 and 168 mm. From February to June the average size of all fish taken increased from 89.1 mm to 137.3 mm.

In February, March, and April there was a distinct correlation between the size of the specimens and the depth at which they were taken. For example on February 19 the fish taken in 3, 6, 9, and 12 fathoms of water averaged 66,2, 75.2, 109.8 and 144.4 mm, respectively. This pattern gradually disappeared and by June could not be detected. Gunter (1945) states that this species enters the bays only during the cooler months. The three specimens I took from the bay occurred in March and April which supports this idea.

Hildebrand (1954) mentions the lack of information on this species' spawning season, stating that it is probably long and concentrated in the fall of the year. He uses Gunter's (1945) capture of a ripe male in August as support for this contention. However, I took several females (135 to 140 mm) from which eggs were oozing May 16, which indicates they also spawn in the spring. Gunter (1945) took two size groups during the spring and summer. It is possible that these may be products of a spring and fall spawn rather than different year-classes.

Larimus fasciatus Holbrook—Banded Drum

Forty-three specimens were taken, some every month, from the Gulf. All but one specimen (1950 mm) were taken in 9 fathoms of water or less. Their relative absence from the deeper stations is surprising as Hildebrand (1954) took 199, mainly from water deeper than 15 fathoms. McFarland (1963) did not record this species from the surf zone.

The temperature range was 12.8–27.8 C, the lowest and highest encountered.

All but the one specimen mentioned above were from 31 to 128 mm with the average size of the catch increasing rapidly during the study. On February 19, the 11 specimens caught were from 37 to 50 mm. In June, 14 specimens were from 98 to 127 mm. Intermediate sizes were caught in March and April. Although Gunter (1945) took only four specimens, all from the Gulf, their sizes correspond to those taken at approximately the

same time of year by me. Hildebrand (1954) took two 40 mm specimens in 3–4 fathoms off Mustang Island in October. Hildebrand and Cable (1934) say they spawn from May to October near Beaufort. The data for the Gulf are consistent with this.

Leiostomus xanthurus Lacépède—Spot

One hundred ninety-two spot were taken from the Gulf, all but four after the middle of May (Table 3). All but twenty were taken at 6 fathoms.

This fish increased in relative abundance from one per cent of the catch on May 16 to 9.5 per cent on June 22.

The spot was taken only in the bay prior to April 16. And only after May 16 was it taken in numbers in the Gulf, indicating that this species may move out of the bays in the late spring. Gunter (1945) found a similar pattern though he stated they leave the bays in mid-winter. His data show that he took them in the Gulf regularly only after May. Hildebrand (1954) stated they are most common in the offshore waters in winter and they move into shallower water during the summer, however my data do not show this.

The temperature range was 14.7–27.8 C.

With the exception of three, the fish were evenly distributed in length between 70 and 128 mm. For this group no separation into possible age groups could be made. Of the three larger specimens two (211 and 189 mm) were the only specimens taken in water deeper than 9 fathoms. The other, (168 mm) was taken in 3 fathoms. All three were collected between March 19 and April 1.

The spawning time of the spot is rather well known. Data from Welsh and Breder (1923), Hildebrand and Cable (1934), Gunter (1945), Kilby (1950), Reid (1954), Dawson (1958) and Springer and Woodburn (1960) suggest a late fall or winter spawn on both the Atlantic and Gulf coast.

Gunter (1945) stated that small, 23 to 93 mm, fish came into the catch in April, suggesting these are the young-of-the-year. It is therefore possible that all of the specimens I took after May 15 were of this age group. Their size range, as previously mentioned, was from 70 to 128 mm. The absence of smaller specimens from the trawl is unexplained.

Menticirrhus americanus (Linnaeus)—Southern Kingfish

Sixty-eight kingfish were taken, mainly during the early part of the study (Table 3). With the exception of one 237 mm specimen taken at 15 fathoms, all were taken in 9 fathoms or less. They disappeared from the trawls in May, reappeared on June 2, and were absent on June 22, probably moving into the shallower surf zone. In support of this, 23 of 28 taken in the surf zone by McFarland (1963) were obtained in May.

The individuals ranged from 51 to 256 mm in length and could be divided into three size groups; nine from 51 to 66 mm; two 237 and 256 mm and the rest from 93–110 mm. The wide range of this last group is consistent with the long spawning season reported by Hildebrand and Cable (1934). Individuals of the 51–66 mm size range were taken at Beaufort mainly in July and August (Hildebrand and Cable, 1934) and as late as October in South Carolina by Bearden (1963), indicating a spring and summer spawning season there. If 50 mm specimens are approximately three months old as Hildebrand and Cable's (1934) data suggest, this species has a much different spawning time in

Texas from that at Beaufort. Specimens between 44 and 52 mm were taken every month except May during my study, suggesting a fall through spring spawning season here. The capture of the young specimens at 3 and 6 fathoms is consistent with Gunter's (1945) belief that the young mature in the Gulf. The temperature range was 12.8–25.5 C.

Menticirrhus littoralis (Holbrook)—Gulf Kingfish

Only 16 specimens of this kingfish were taken. Of these, 15 were taken in 3 fathoms of water between February 19 and April 1. All were between 132 and 181 mm. The water temperature range was 14.2–18.3 C. One 189 mm specimen was taken at 6 fathoms on April 1. Its disappearance from trawls as the water temperature increased is roughly coincidental with Gunter's (1945) and McFarland's (1963) capture in the shallow surf zone. Springer and Woodburn (1960) found this species to be much more abundant than *americanus* in the Tampa Bay area.

Micropogon undulatus (Linnaeus)—Atlantic Croaker

A total of 2,372 croakers were taken during this study. They occurred in every month, though fluctuating radically as shown in Table 3. After a catch of 96 on February 19 the numbers dropped off to 12 or less until May 16 when 1,114 were taken from the Gulf. Their relative abundance was 52.1 per cent of the catch on June 2. All but five occurred at 3 and 6 fathoms until June 22 when 220 of the 426 taken were caught at 9 fathoms. The temperature range was 13.2–27.8 C.

At the time of the great abundance of croakers in the Gulf catches (February 19 and May 16 through June 22) only one croaker was taken at the bay station. However, during the intervening dates when the croaker was relatively scarce in the Gulf trawls, 123 croakers of a similar size range were taken at the single bay station. Though scanty, the data suggest that the croaker entered the bay during this interval. McFarland's (1963) data do not suggest that they moved into the surf zone when they apparently left my study area. Hildebrand (1954) also stated that they became rare offshore in the spring. Gunter (1945) also took the majority of croakers from the Gulf after May and the majority of croakers from the bays before May.

The size range was 34–202 mm. From a length-frenquency diagram constructed and the abundant literature on this species it would seem that all but two specimens belong to a single group spawned the previous year. The two deviants, 155 and 202 mm specimens, were taken February 19 and April 1, respectively. The rest were between 34 and 140 mm.

The modal size of the group increased rapidly from 40 to 60 mm (95 per cent of the specimens) in February to 100 to 130 mm (83 per cent of the specimens) in June.

Data from Pearson (1929) and Gunter (1945) from Texas along with life history data from other areas such as Hildebrand and Cable (1930), Suttkus (1954) and Springer and Woodburn (1960) suggest an extended spawning season sometime between October and March. Gunter (1945) found ripe or ripening croakers in October, November and December from here. All of the juveniles I took were probably spawned within this time range.

Stellifer lanceolatus (Holbrook)—Star Drum

A total of 616 star drum were caught during this investigation. They were taken in every month, though present in the greatest numbers on June 2 as shown in Table 3. Their greatest relative abundance, however, occurred in April when they constituted 24.5 per cent of the catch. All but eight were taken at 3 and 6 fathoms. Hildebrand (1954) states that they are rare on the brown shrimp grounds which are mainly more offshore than my study area, so this can be called an inshore species, though McFarland took none from the surf zone.

Of the 112 fish, from 42–112 mm long, taken February 19 (52 at 3 fathoms, 60 at 6 fathoms) it was noted that all 21 specimens over 77 mm occurred at 6 fathoms. It seems unlikely that this is a coincidence; howeve, no size-depth correlation could be detected in the subsequent catches.

The temperature range was 12.8–27.8 C.

The size range was 40–157 mm. It is almost certain that at least three year classes were taken during the study, but from a length-frequency table only two distinct size groups appeared. A single 40 mm specimen taken June 2 was undoubtedly of this spring's spawn. The others taken in that month were at least 85 mm long. The remainder, in spite of a wide variation in size (for example, from 44–140 mm on March 19), could not be separated into age groups though young-of-the-year, one and two-year old fish were probably present. Gunter (1945) also found that by January the young-of-the-year group apparently had blended with the adults so they could not be identified.

Welsh and Breder (1923) say that spawning occurs in late spring and early summer on the Atlantic Coast. Gunter (1938) found ripe females between May and June in Louisiana. Gunter (1945) found ripe fish here in April. Of the specimens I took, three ripe females, 139, 147, and 149 mm long were taken in May. However the 40 mm specimen taken June 2 is too large to have been spawned in May. According to the growth rate postulated by Hildebrand and Cable (1934) this specimen would probably have been spawned in April. Even more interesting are the specimens between 42 and 70 mm taken as early as February 19. Again according to Hildebrand and Cable's (1934) growth rate these juveniles are approximately two months old. Even if the growth slows down in the winter these must have been spawned after mid-summer. This is the first evidence I can find of other than a spring spawning season in Texas.

Lagodon rhomboides (Linnaeus)—Pinfish

Thirty-one pinfish were taken in the Gulf between February 19 and June 22. All but five were taken in 3 and 6 fathoms, those being taken in one haul at 9 fathoms on February 19, indicating a shallow Gulf habitat in the spring and summer. They were absent from the Gulf trawls in March and May but were taken from Aransas Bay both months. The bay catches show this species to be much more common there than in the shallow Gulf at all times. The size range was 86–128 mm, with the average size increasing as the study progressed. None appeared to belong to the 0-year age class. The spawning season has been well established by Caldwell (1957) as occurring in late fall and winter offshore. Gunter (1945) took this species from the Gulf only in November and January. The temperature range was 13.8–27.5 C.

Stenotomus caprinus Bean—Longspine Porgy

One 38 mm specimen was taken May 2 and two (51 and 64 mm) on July 13, all in 15 fathoms. The temperature range was 20.9–25.7 C. Gunter and Knapp (1951) list the first record of the occurrence of this species from Texas. Hildebrand (1954) took over 10,000 of this species mainly in deeper water. The size of these specimens corroborates his statement that this species spawns in the spring. This species was not taken in any other faunistic study in the Gulf which I reviewed.

Chaetodon ocellatus Bloch—Spotfin Butterflyfish

A single 39 mm specimen was taken from the three fathom station in the Gulf on April 1. The temperature was 18.3 C. This species has been reported by Hildebrand (1954) to occur commonly along the Port Aransas jetties in the summer, so its capture in April was unexpectedly early. Even more unusual than the specimen mentioned above were two (29 and 31 mm) specimens taken March 4 and 19 in Aransas Bay. The water temperatures were 13.8 and 17.3 C, respectively. To my knowledge, the capture of these specimens is the first record of other than a summer appearance at Port Aransas. None were taken by Gunter (1945) nor in any of the Florida studies reviewed, except that of Longley and Hildebrand (1941) at Tortugas, Fla. Baughman (1950) reported this species from the nearby Lydia Ann Channel but did not give any dates.

Astroscopus y-graecum (Cuvier)—Southern Stargazer

Four stargazers were taken, all at 3 fathoms. Two (62 and 48 mm) specimens were taken February 19. Another (67 mm) was taken on March 2 and a 49 mm specimen on April 1. The temperature range was 13.8–19.4 C. Gunter (1945) took this species in the summer and winter so it is apparently a permanent, though rare, resident. Hildebrand (1954) did not take this species during all of his offshore trawling so it may be an inshore species only. It was taken both in the surf zone and Aransas Bay by Gunter (1945). However, none were taken in the surf zone by McFarland (1963).

Trichiurus lepturus Linnaeus—Atlantic Cutlassfish

Three hundred ninety-four cutlassfish were taken throughout the study as shown in Table 3. They were present throughout the temperature range encountered (12.8–27.8 C).

The majority ranged from 215 to 502 mm. The average size of the fish increased from 269.5 mm in February to 384.4 mm in June. Only two distinct size groups were present.

On May 16, four juvenile fish measuring 47, 56, 69 and 94 mm were found entangled in the mesh of the trawl at 12 and 15 fathoms. The rest of the cutlassfish ranged from 257 to 502 mm at that time. On June 2 four other smaller fish were taken at 12 and 15 fathoms. These ranged from 110 to 138 mm. It seems that this is the first positive indication that this species spawns in the Gulf. The absence of data recording small fish in the bays also supports an hypothesis of offshore Gulf spawning. Gunter (1938) reported "attenuated young" in April in Louisiana, which he attributed to a previous summer or fall spawn. Hildebrand (1954) noted "an abundance of small silver eels entrapped in the meshes" in July. These undetailed accounts contribute little to the life history of

this species. Neither Gunter (1945) nor any of the Florida investigators reported any life history information.

Bollmannia communis Ginsburg

Twenty-two specimens were taken between February 19 and June 2. All but one (in 12 fathoms) were taken in 15 fathoms. Hildebrand (1954) is the only author of those reviewed who took this species. While he took only 770 specimens, he described it as characteristic of the brown shrimp grounds, so this is definitely a deeper-water species.

They were all rather evenly distributed between 47 and 104 mm and no separation into age groups could be made. The smaller specimens occurred throughout the study period so no estimate of growth was possible.

The temperature range was 14.4–24.3 C.

On May 2, a ripe female (86 mm) was taken at station 15. I could find no other record of this species' spawning season.

Gobionellus gracillimus Ginsburg—Slim Goby

Twelve specimens were taken between April 16 and June 2, all in 15 fathoms. The temperature range was 18.1–24.3 C. All were between 68 and 113 mm. Of the comparable studies, only Hildebrand (1954) took two specimens from the Gulf, in December and May, in approximately 20 fathoms. Apparently this rare species occurs mainly in deeper water. The only other record from this area is that of Ginsburg (1953) who described the species. He did not state from what depth his specimens were taken. Apparently nothing is known of its spawning habits.

Lonchopisthus lindneri Ginsburg—Swordtail Jawfish

One 103 mm specimen was taken at 15 fathoms on March 2. The water temperature was 14.4 C. Hildebrand (1954) took only one from the Texas coast, but did not state the depth. These, together with Ginsburg's (1942) type specimens are the only records the author could find for the Texas coast. None have been taken from Florida.

Brotula barbata (Bloch and Schneider)—Bearded Brotula

Two specimens (72 and 79 mm) were taken at 12 and 6 fathoms, respectively, on March 19. Another (80 mm) was taken at station six on April 11, at night. The March 19 collection was made slightly earlier in the day than the others, especially considering sunrise time, so that this capture may also reflect nighttime activity. The temperature range was 15.2–19.3 C. Baughman (1950) listed the first record west of the Mississippi, but did not know where it was caught. Hildebrand (1954), trawling mainly at night, took 39 specimens from the Texas shrimp grounds. He states that this species probably moves into water deeper than 17 to 24 fathoms in the winter, as he took none then. However, it would seem unlikely that the small specimens I took in March could have made the journey back to 6 fathoms since winter. Perhaps his data reflect their reluctance to come from their burrows during the colder water temperatures. It was not taken during any of the Florida studies reviewed except that of Longley and Hildebrand (1941) at Tortugas, Florida.

Lepophidium brevibarbe (Cuvier)—Shortbearded Cusk-eel

Two specimens were taken, one (199 mm) on March 2 and another (146 mm) on March 19, both at 15 fathoms. The bottom temperatures on those dates, respectively, were 14.4 and 15.8 C. Gunter (1945) took only one adult in the months of January and March, while Hildebrand (1954) counted 710 from the Texas shrimp grounds, all at depths of at least 12 fathoms. The data indicate that this is a deep water species.

Ophidion welshi (Nichols and Breder)—Crested Cusk-eel

One specimen (194 mm) was taken in 6 fathoms on February 19. The water temperature was 14.6 C. Gunter (1945) took only two specimens, and they were taken in March. Hildebrand (1954) took only nine. This species is probably more abundant in the shallow Gulf water than the above records would indicate, because one 15 minute haul at night on April 11, produced four specimens (95 to 100 mm). The temperature then was 19.3 C. Apparently this species burrows during the day, and emerges at night. The few specimens taken by Hildebrand (1954), who collected much of his data at night, may be due to the fact that the habitat of this species is in shallower water than in the area he worked most extensively.

Peprilus paru (Linnaeus)—Northern Harvestfish

Ten harvestfish were taken in the Gulf, one each on February 19 and March 19 and eight in June. Six of the specimens taken in June were from 29 to 45 mm. All others were from 62 to 110 mm. The temperature range was 14.6–27.5 C. All were taken in 6 fathoms of water or less. However, Hildebrand (1954) took this species throughout the year, mainly in deeper water than my study area so my data are not indicative of its distribution. Gunter (1945) took only six specimens during his study, all from the Gulf. McFarland (1963) calls this a summer resident of the surf zone.

The small specimens taken in June would indicate a spring spawning season. Joseph and Yerger (1956), however, took four specimens, 31 to 36 mm, in September near Alligator Harbor, Florida.

Poronotus triacanthus (Peck)—Butterfish

Two hundred-six butterfish were taken, some in every month (Table 3). The highest relative abundance (16.4 per cent of the catch) occured on April 16 though more fish were taken on May 2. As the number caught declined in May and June, the fish were being taken only in deeper water, while during the earlier months they were apparently more evenly distributed over the study area. Between February 19 and April 1, 12 to 14 were taken at each station. On May 16, all 13 fish were taken in 12 and 15 fathoms and on June 22 only at 15 fathoms. Gunter (1945) took no specimens in July. Though his numbers were also small, this may indicate a movement to deeper water by then. McFarland's (1963) data indicate this species does not enter the surf zone.

The temperature range was 12.8–25.7 C.

They occurred in at least two size groups. On February 19 five juveniles (from 28 to 37 mm) were taken with two adults, 112 and 151 mm. Subsequently, only one 168 mm specimen taken in April could be separated from the remainder on the basis of size. The

size ranges in the following months were wide (in March, 22 to 118 mm; in April, 25 to 126 mm; and in May, 47 to 132 mm), but insufficient numbers were taken to distinguish age groups from a length-frequency diagram. In June only 19 butterfish were taken.

Gunter (1945) took his smallest (over 37 mm) specimens in June. The winter and spring occurrence of young in my trawls would suggest at least a winter spawning season, however the large size range encountered then indicates they may also spawn in the fall. Hildebrand (1954) mentions the well-known fact that young often are seen in the shelter of the bell of the jellyfish *Stomolophus meleagris* in this area in the spring.

Probably due to its pelagic existence, no butterfish were taken during any of the Florida investigations reviewed though it occurs there (Briggs, 1958).

Polydactylus octonemus (Girard)—Atlantic Threadfin

Two hundred twenty-seven threadfins were taken, all after March (Table 3). The temperature range was 17.3–27.8 C. All but one (a 176 mm specimen in 9 fathoms) were taken from 3 and 6 fathoms. The decline in numbers after the maximum on May 16 probably reflects the fish moving into the shallower surf zone. McFarland's (1963) data for the beach zone also support this contention. The maximum numbers of this species occurred in his beach samples after July.

The size range was 71–176 mm. In spite of this wide range, when the lengths were grouped on a length-frequency table, no biomodality could be detected. The average size of the fishes caught increased gradually from 84 mm on April 1 to over 125 mm in June. The smallest fish taken June 22, was 45 mm longer than the smallest taken in April. Gunter (1945) also noted that the fish grow rapidly. This probably represents a rapid rate of growth rather than larger specimens moving into the study area as the season progressed. Gunter (1945) noted a distinct group of smaller (23 to 43 mm) fish in June. However, when or where this species winters or reproduces is apparently unknown.

Of the Florida surveys reviewed, only that of Springer and Woodburn (1960) mentions this species, a single specimen taken in September.

Prionotus tribulus (Cuvier)—Bighead Searobin

Sixteen specimens were taken throughout the study, to make it the most abundant searobin in my trawls. Gunter (1945) also found this species of searobin to be the most abundant. A few individuals were taken in all depths except 15 fathoms. Hildebrand (1954) stated this species apparently prefers waters shallower than 12 fathoms, as indicated by my data. The temperature range was 12.8–24.6 C.

All but one specimen (152 mm) were from 21 to 73 mm. Specimens less than 33 mm were taken both in February and June indicating a long, possibly fall and winter spawning season. Gunter (1945) also took his smallest specimens in the spring. Hildebrand (1954) took a ripe female in August. Data collected by Reid (1954), Kilby (1950) and Springer and Woodburn (1960) from Florida also indicate a fall spawning season there.

Prionotus pectoralis Nichols and Breder—Blackwing Searobin

One 133 mm specimen was taken in 15 fathoms on May 2. The bottom temperature was 20.9 C. Gunter (1945) took three specimens between 102 and 142 mm from the

Gulf in March. Hildebrand (1954) identified 334 specimens during his study, all from depths greater than 12 fathoms, so this species may be said to prefer deeper water. None were taken in any of the Florida studies mentioned.

Prionotus rubio Jordan—Blackfin Searobin

Two small (38 and 52 mm) specimens were taken in 6 and 12 fathoms, respectively, on June 22. The temperature range was 25.6–27.8 C. Hildebrand (1954) took 17,900 specimens, indicating it prefers deeper water.

Hildebrand (1954) took ripe females in January and said it apparently has a long spawning season. My data would seem to indicate a fall and winter spawn. Gunter (1945) did not take this species, nor was it taken in any of the Florida studies.

Porichthys porosissimus (Cuvier)—Atlantic Midshipman

Seven midshipmen were taken, two on February 19 at the three fathom station and one in 15 fathoms on March 2, then four in May in 12 and 15 fathoms. The water temperature at the respective stations on February 19 and March 2 was 14.7 and 14.4 C. The water temperature where they were taken again in May was from 20.9 to 22.8 C. Hildebrand (1954) took 13,000 midshipmen, indicating this species prefers deeper waters but did not state when he took them. Gunter (1945) took no specimens from the Gulf, but found six in the bays between April and November. Springer (1957) says they leave the coast completely between October and April, and return to spawn in the spring. The capture of three of my specimens in February and March indicates all do not leave that soon. However, the specimens taken in May might indicate their return as they have been taken regularly in the Tide Trap as the Institute of Marine Science since then. A (136 mm) ripe female taken May 2 by me, and a previous one by Hildebrand (1954) in March, corroborate Springer's (1957) idea concerning spawning time.

Anclyopsetta quadrocellata Gill—Ocellated Flounder

Thirteen specimens taken from the Gulf between February 19 and May 2 fell into two distinct size ranges, one from 36 to 58 mm, the other from 170 to 182 mm. Gunter (1945) found a similar small sized group of fish in March and April. Thus it would seem likely that they spawn in the fall or winter here depending on the growth rate. The temperature range was 13.6–23.6 C.

Eleven of the 13 were taken between 9 and 15 fathoms. However, Gunter (1945) took them from the bays and Hildebrand (1954) took them during his study in deeper waters. No seasonal pattern could be established from their data.

Etropus crossotus Jordan and Gilbert—Fringed Flounder

Sixteen specimens of the fringed flounder were taken in the Gulf between February 19 and April 16, all from 6 to 12 fathoms. All but two were taken in February and March, indicating they may leave the area in the summer. Gunter's (1945) data also support this idea. Hildebrand (1954) states that it is rarely found in water deeper than 17 fathoms. But this migratory pattern, if present, is obscure due to the lack of data available. The temperature range was 12.8–18.8 C.

The size range encountered was 49 to 142 mm. The capture of the two smallest specimens, 49 and 67 mm in February is in agreement with the extended spring and summer spawning season suggested by Reid (1954).

Citharichthys spilopterus Günther—Bay Whiff

Fifteen whiffs were caught between March 19 and June 22. They were present every month through a temperature range of 15.2–25.6 C. Ten were taken in 12 and 15 fathoms and five in 6 and 9 fathoms. This species occurred in the shallower trawls only after June 2 which may indicate a movement inshore. Gunter (1945) took this species in the bays only after May which also supports this idea.

The five specimens taken in June were from 55 to 85 mm while all other specimens were between 102 and 131 mm, indicating an age difference.

Paralichthys albigutta Jordan and Gilbert—Gulf flounder

Three Gulf flounders were taken, one each on February 19, March 2, and May 2. They measured 211, 221, and 269 mm, respectively. The temperature range was 12.8–23.6 C. Two were taken at 9 and one at 6 fathoms.

Both Gunter (1945) and Hildebrand (1954) comment on the rarity of this species compared to *P. lethostigma.* Hildebrand (1954) stated that this species probably prefers shallower waters which may explain its relative absence from his study area. Gunter (1945) took three *albigutta* and five *lethostigma* from the Gulf but found 245 *lethostigma* to nine *albigutta* in the bays. It seems from their data that neither is particularly common in the shallow Gulf, as my study indicates. Reid (1954) found this species to be most abundant at Cedar Key between February and May.

Syacium gunteri Ginsburg—Shoal Flounder

Two hundred forty-nine specimens were taken in the Gulf, all but six in 12 and 15 fathoms, indicating it occurs mainly in deeper waters. Hildebrand (1954) took 66,000, also mainly from water deeper than 12 fathoms. Gunter (1945) took all his specimens from the Gulf, indicating they do not enter the bays. The temperature range was 13.6–25.7 C. Its greatest abundance (Table 3) occurred on February 19 and March 2 when it constituted 8.2 and 13.2 per cent of the catch, respectively. Afterwards it dropped off rapidly, perhaps due to an offshore movement.

The specimens caught ranged from 46 to 155 mm. When an attempt to construct a length-frenquency table was made, a mode of fish between 80 and 100 mm found in February and March could not be followed in later samples due to the small number taken, so a growth rate estimate could not be made. The large size range, together with the rather even distribution of sizes indicates a long spawning season. The appearance on June 2 of two smaller specimens (46 and 47 mm) was the only definite indication of another age class. These were probably spawned the preceding fall or winter, depending on the growth rate. All other specimens at this time were from 80 to 142 mm.

Achirus lineatus (Linnaeus)—Lined Sole

Two 101 mm specimens were taken at 9 fathoms on March 2 and 19. The water temperatures were 12.9 and 15.6 C, respectively. Gunter (1945) took 25 specimens from the Gulf, mainly in the spring and winter, while Hildebrand (1954) took them mainly in more offshore waters only in October. The data here is insufficient to establish a seasonal distribution pattern. Springer and Woodburn (1960) took them in every month in Florida, while Reid (1954) found them to be absent between January and March at Cedar Key.

Kilby (1950) believed them to spawn in late summer or early fall while Reid's (1954)

data suggested an earlier spawning season. No spawning records were found for the western Gulf.

Symphurus plagiusa (Linnaeus)—Blackcheek Tonguefish

All specimens of tonguefish obtained in this study are considered to be *S. plagiusa*. Ginsburg (1951) described a new species, *civitatum*, which was recognized by Hildebrand (1954) in his study of this area. The main distinguishing characters which Ginsburg (1951) listed are: *plagiusa*, a black spot on the opercle of many specimens and usually ten caudal rays; and *civitatum*, no black spot and usually 12 caudal rays. Other characters which he listed overlap widely and cannot be used as diagnostic. I obtained specimens with a black opercular spot with both 10 and 12 caudal rays, and others with no opercular spot which had both 10 and 12 caudal rays. Plotting the distribution of tonguefish against depth yielded no pattern suggesting different ecological preferences of 10- and 12-caudal rayed specimens. My data suggest that *civitatum* may be a synonym of *plagiusa*.

Eighty-nine specimens were taken from the Gulf as shown in Table 3. Their maximum relative abundance (six per cent of the catch) occurred on March 2. Over 80 per cent were taken in 6 and 9 fathoms. This indicates a shallow distribution, although Hildebrand (1954) took 48 specimens which he called *civitatum* from water deeper than 10 fathoms. Table 3 shows they became less abundant in the shallow Gulf as the water temperature increased. Gunter (1945) also found this to be true, although a movement to deeper water was not detected. Neither were they taken by him from the nearby bays during the summer, so their migratory pattern is obscure. The temperature range was 12.8–26.5 C.

All specimens were between 62 and 156 mm. There were no distinct size groups, and from their sporadic appearances of different sized individuals, no estimate of growth rate was made.

Monacanthus hispidus (Linnaeus)—Planehead Filefish

A single 56 mm specimen was taken on March 2 from 9 fathoms. The water temperature was 12.9 C. Gunter (1945) did not take this species, while Hildebrand (1954) counted 11 from the Texas shrimp grounds. Although uncommon, it appearently prefers deeper waters, perhaps near the reefs.

This species is more abundant in the shallow eastern Gulf as Springer and Woodburn (1960) and Reid (1954) took 125 and 90 specimens, respectively, from Florida.

Balistes capriscus Gmelin—Gray Triggerfish

One large (302 mm) specimen was taken from 9 fathoms on May 2. The bottom water temperature was 23.6 C. It is apparently unusual for specimens this large to be taken this far from their normal reef habitat. Gunter (1945) took only one small specimen (59 mm) from the Gulf in September.

Lagocephalus laevigatus (Linnaeus)—Smooth Puffer

Seven specimens were taken, all between May 16 and June 22. The temperature range was 22.8–25.7 C. This species was taken only from 9, 12 and 15 fathoms. Hildebrand (1954) took 498 from the Texas shrimp grounds, so this species evidently prefers deeper waters. Gunter (1945) did not take this species.

All specimens were between 49 and 99 mm. Springer and Woodburn (1960) recorded two spent females from the Tampa Bay area in March and May, which is the only data I could find regarding the spawning season of this species. The small specimens I took would seem to indicate a later, possibly fall, spawning season in the offshore waters of South Texas.

Sphoeroides nephelus (Goode and Bean)—Southern Puffer

Fifteen specimens of this puffer were taken from the Gulf. They were taken in every month except May; however 12 of the 15 occurred at the 3 and 6 fathom stations in February and March. McFarland (1963) took them from the surf zone in January and March, while Hildebrand (1954) took 505 from the Texas shrimp grounds, which are mainly in water deeper than 15 fathoms, but reported no seasonal pattern. Gunter (1945) says this species may move out of the bays into deeper water as the water temperature drops, which McFarland's (1963) and my data indicate.

The size range of the 12 which were taken in 3 and 6 fathoms was 70–108 mm. On April 1 a 50 mm specimen was taken in 9 fathoms, and on June 22, specimens 25 and 26 mm were taken at the 12 and 15 fathom stations. Gunter (1945) took 13 mm specimens in May, which he called *S. marmoratus*. Hildebrand (1954), however, says they were *S. nephelus*. These data indicate a spring spawn. Springer and Woodburn (1960) found specimens less than 20 mm near Tampa between November and June which indicated the spawning season there begins in the fall. The 50 mm specimen I took in April might have been spawned then.

Chilomycterus schoepfi (Walbaum)—Striped Burrfish

Three burrfish were taken from the Gulf during this study. Two adults (155 and 179 mm) were taken in March from the 3 and 6 fathom stations, respectively, when the bottom water temperature was 13.2 and 17.0 C. The other, a small (30 mm) specimen, was taken from 6 fathoms on June 2. The bottom temperature then was 25.2 C. Gunter (1945) took none from the Gulf, believing them to be absent due to the lack of their food there, which he suggested to be normally reef animals. Reid (1954) subsequently agreed with Gunter; however, Springer and Woodburn (1960) did not note a dependence on this type of food when they analyzed 17 stomachs. My data show they do inhabit at least the shallow Gulf in the spring, although in small numbers. Hildebrand (1954) also took specimens (13) from the Gulf, but did not mention the depth at which they occurred. He did say they were most abundant in the summer.

My capture of the 30 mm specimen in June corroborates the suggestion by Reid (1954) and Springer and Woodburn (1960) that this species spawns in the early spring.

Antennarius radiosus Garman—Singlespot Frogfish

One hundred-ten frogfish were taken between March 2 and May 2. Of these, 77 were taken at 15 fathoms and only four were taken as close to shore as 6 fathoms. The four inshore captures occurred on March 19 and April 1 when the bottom temperatures there were 16.5 and 17.3 C. My data indicate a subsequent offshore migration. Hildebrand (1954) termed them common in the deeper waters in which he worked. Gunter (1945) did not take this species; all of the specimens I took could have passed through a trawl with the size mesh he used.

The size range was small (26–65 mm) and different age groups were not apparent.

It seems that the extent of life history data for this species is the list of stomach contents found by Hildebrand (1954), therefore no spawning season was postulated for my captures.

As Hildebrand (1954) indicated, they are voracious feeders; one 43 mm specimen which I caught had just managed to eat an 88 mm *Gobionellus* sp. and many others had stomachs greatly distended by food or water, the latter apparently a protective reaction to being captured.

Halieutichthys aculeatus (Mitchill)—Spiny Batfish

A single 57 mm specimen was taken on March 19 from 9 fathoms. The water temperature was 15.6 C. Hildebrand (1954) took 163 specimens from the Texas shrimp grounds, all from water 12 fathoms or deeper, indicating this species prefers more offshore waters. That of Woods (1942) is the only other published record from this area.

Ogcocephalus sp.—Batfish

The four short-nosed batfish taken are identified here only to genus, following the precedent of Hildebrand (1954), who mentioned the need for a revision of this genus.

Two specimens were taken on March 19, a 207 mm one from 9 fathoms and another (58 mm) from 12 fathoms. On April 16 an 81 mm batfish was taken in 12 fathoms and another (199 mm) was taken on May 2 at the 9 fathom station. The temperature range was 15.2–23.6 C.

Hildebrand (1954) took 1,330 specimens of this genus from 12–37 fathoms and said it was the most abundant batfish on the brown shrimp grounds, so it obviously prefers deeper waters than those in which I worked.

Gunter (1945) took 17 batfish from the Gulf which he identified as *O. naustatus* and *O. vespertilio*. My specimens fit the description of neither.

General Discussion

As pointed out in the introduction, the segment of the shallow Gulf in which I worked was the least studied of the major marine habitats in this vicinity. Gunter (1945) studied the nearby bays extensively using both trawl and seines. McFarland (1963) did a seasonal study of the surf zone with a beach seine, while Hildebrand (1954) trawled mainly in waters deeper than 15 fathoms. My study, then, adds to the knowledge of the fishes in the 3–15 fathom zone of the Gulf in this region.

While subject to different bias due to different sampling techniques, all four studies usually indicated the same general migratory pattern for each species. However, the results of my day-night trawling on April 11 indicated that the diurnal activity of certain species, such as *Trichiurus lepturus*, can greatly affect the results obtained by any sampling technique, and therefore should be considered by any future investigator.

As indicated by my catches, as well as those of Gunter (1945), the Sciaenidae could be called the dominant group of bottom fishes in the shallow Gulf. *Micropogon undulatus, Cynoscion arenarius, C. nothus* and *Stellifer lanceolatus* alone comprised nearly 57 percent of the total catch (Table 3).

During the interval I studied, three basic migratory patterns were apparent:

First, a general offshore movement with increasing water temperatures was indicated for *Poronotus triacanthus, Urophycis floridanus, U. cirratus, Syacium gunteri,* and *Antennarius radiosus.* Evidently these species prefer colder waters.

Second, a general inshore movement was detected. My data indicate this to be the behavior of: *Menticirrhus americanus, M. litoralis, Polydactylus octonemus, Vomer setapinnis, Lagocephalus laevigatus, Chloroscombrus chrysurus, Citharichthys spilopterus,* and *Synodus foetens.* A movement into the surf zone was indicated for three of these species: *M. americanus, M. litoralis* and *P. octonemus.*

Third, *Micropogon undulatus* seemed to move into and out of the bays during the study interval.

In general, those species Gunter (1945) reported to move from Gulf to bay moved inshore in my area at that time.

Briggs (1962) has mentioned the importance of the 20 C February mean surface water isotherm in forming the zoogeographic boundary between tropical and warm temperate marine fauna. The significance of this isotherm is supported by the appearance of the "summer" species and the disappearance of the "winter" species from the trawls at approximately the same time as the occurence of an average bottom water temperature of 20 C (Table 3).

The remainder of the species were either present in the area throughout the study time, or were taken in insufficient numbers to indicate migratory patterns.

Those species for which no migratory pattern was indicated taken most commonly or only inshore were: *Anchoa* sp., *Bagre marinus, Galeichthys felis, Orthopristis chrysopterus, Larimus fasciatus, Lagodon rhombodies, Chaetodon ocellatus, Sphoeroides nephelus and Chilomycterus schoepfi.*

Others for which no migratory pattern was indicated taken most commonly or only offshore were: *Etrumeus teres, Saurida brasiliensis, Diplectrum arcuarium, Centropristis philadelphicus, Trachurus lathami, Bollmannia communis, Gobionellus gracillimus, Lepophidium brevibarbe, Halieutichthys aculeatus* and *Ogcocephalus* sp.

Finally, as the water temperature increased the catch was marked by a general increase in the numbers caught (Table 3). However, the species diversity of the bottom fishes appeared to decrease. Nineteen species were taken in the trawls only during the first part of the study while twelve species appeared in the catches only during the latter part of the study.

Acknowledgments

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Mollusks from the Deeper Waters of the Northwestern Campeche Bank, Mexico

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Abstract

Photographic plates, environmental and distributional data are given for a collection of 129 species of gastropods and 46 species of pelecypods in 22 samples from 15 to 120 fathoms of water along the outer part of the northwestern Campeche Bank. Adjacent depth zones have more species-in-common than widely separated zones. Many species seem to prefer a calcarenite substrate. Some of the mollusks collected on the continental shelf may be relicits of a lower sea level.

Introduction

The Campeche Bank is included in the zoogeographical area called the Caribbean Province (Rehder, 1954, p. 471). Areas inhabited by the Caribbean fauna include the shelves bordering the Gulf of Mexio, Caribbean Sea and Atlantic Ocean off the coasts of Mexico, Central America, part of South America, the West Indies, the Bahamas, Bermuda, and the outer shelves off Louisiana, Texas and part of the Atlantic coast of the United States. A map showing the extent of the Caribbean fauna is given in Warmke and Abbott (1961, p. 319).

The present paper lists and illustrates 129 species of Gastropoda and 46 species of Pelecypoda from 22 samples collected in water 15 to 120 fathoms deep along the outer part of the northwestern Campeche Bank (Fig. 1). Most species have been previously described from the Caribbean, but few were known from the Campeche Bank. Of the 130 species of mollusks reported by Rice and Kornicker (1962) from the shallow waters of Alacran Reef, situated near the northern edge of the Campeche Bank, only 11 were also collected in deeper water. Of the species listed in the present paper, eight were previously reported from the Campeche Bank by Springer and Bullis (1956), two from the shallow waters of Progreso on the northern Yucatan coast by Baker (1891), and six from the Laguna de Terminos at the southwestern base of the Yucatan Peninsula by Garcia-Cubas, Jr. (1963). Many species have been reported from the deeper waters of the Gulf of Mexico by Rehder and Abbott (1951).

Description of Area

Bathymetry.—The continental shelf off the Yucatan Peninsula of Mexico is a broad limestone platform covered by a veneer of carbonate sediments. The shelf is listed on

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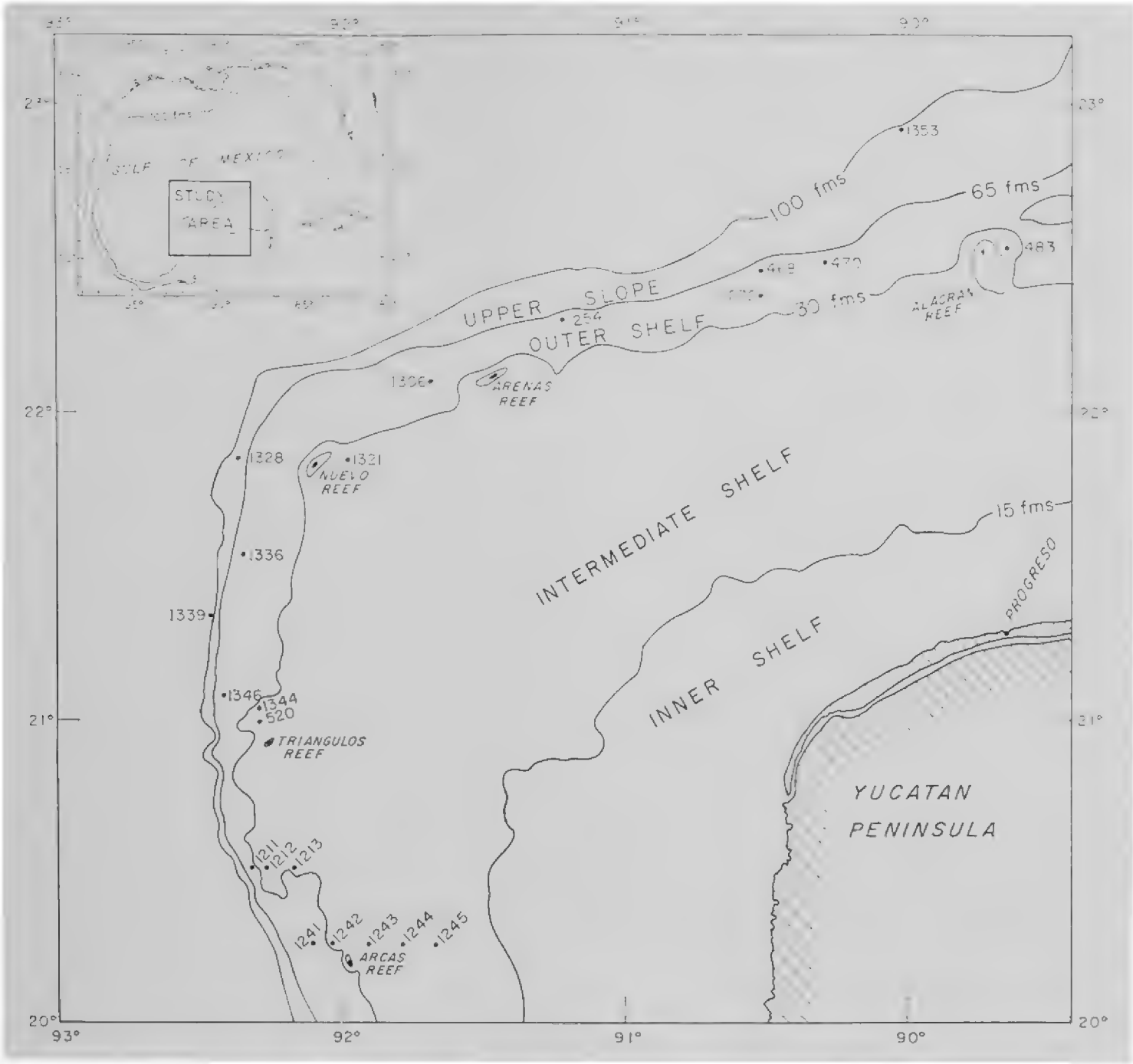

FIG. 1. Sample location map and subdivisions of the Campeche Bank.

maps as the Campeche Bank or Banco de Campeche and is defined by the 100-fathom bathymetric curve which lies about 155 miles from the northern coast of Yucatan and about 120 miles from the western coast; the 100-fathom contour lies close to the northeast corner of the peninsula.

Shoal areas formed by banks and reefs are found within 30 miles of the coastline, but large coral reefs and banks are restricted to a fairly narrow zone that lies within, and more or less follows the 30 fathom contour, except northeast of Alacran Reef where two large submerged banks lie between the 30 and 40 fathom curves.

From the coast of a peninsula to the reef zone the bank slopes gently, but unevenly at a gradient of 2–3 feet per mile. The slope increases gradually on the outer side of the reef zone until it finally becomes a precipitous scarp that drops to the abyssal plain. The change in gradient on the outer side of the reefs is more gradual along the northern than along the western edge of the bank, which is bordered by the Campeche Canyon. From Alacran Reef to the 100 fathom contour the slope gradient is about 14 feet per mile, whereas from Arcas Reef, near the western edge of the bank, the slope gradient is about 32 feet per mile. Alacran Reef lies about 30 miles in from the 100-fathom con-

tour whereas Arcas Reef is only about 13 miles; other reefs in the reef zone are situated from 9 to 17 miles from the 100 fathom curve.

In this paper the Campeche Bank is subdivided into an inner shelf which extends from the 0 to 15 fathom curves; an intermediate shelf from 15 to 30 fathoms, which includes the reef zone, and an outer shelf from 30 to 65 fathoms. The latter depth is approximately at the upper boundary of the continental slope.

Currents.—Water from the Yucatan Channel between Yucatan and Cuba travels westward across the Campeche Bank with a velocity of ½ to 1½ knots 20 to 30 miles offshore. Over the western part of the Bank currents move southwestward into the Bay of Campeche. From October to May, in the Bay of Campeche, a counterclockwise current forms which occasionally extends northward to Arcas Reef (U.S. Navy, 1952).

Temperature and Salinity.—Surface water temperatures are as low as 23 degrees C. in the winter and as high as 29 degrees C. in the summer (Fuglister, 1947). Except along the eastern edge of the Bank where upwelling occurs, temperatures at 15 to 30 fathoms remain within a degree of the surface temperature. Below 15 to 30 fathoms the temperature decreases about 0.1–0.35 degrees C. per fathom. Surface waters of the Bank have salinities which range between 36.00 to 36.35 parts per thousand (Parr, 1935).

Sediments.—The sediments of the Campeche Bank from about 89 degrees 30 minutes to 91 degrees latitude have been described by Cann (1962). Sendiments near the shore and out to 10 to 20 fathoms contain many large shell fragments and consist mostly of sand-sized material of which mollusk fragments comprise a major part; similar sediments occur along the windward edge of Alacran Reef. At the periphery of the inner shelf and out to 25–30 fathoms the sediments have fewer large shell fragments, are in general smaller in size, and mollusk fragments, which are the major skeletal component, comprise a lower percentage of the sand. Sediments in water deeper than about 30 fathoms are generally finer and have a high percentage of planktonic remains (pteropods and foraminifera). Sediments containing a high proportion of oolitic grains occur in large patches at depths between 25 and 40 fathoms, and in small patches at a depth of about 8 fathoms. Patches of sediment containing a high percentage of coralline algae occur at depths between 25 and 28 fathoms and nearer shore in about 23 fathoms. Williams (1963, Fig. 9) indicates that oolitic sediment is present on the outer shelf at least as far south as Triangulos Reefs. Clay, which is probably transported by the counterclockwise current prevalent during part of the year, seems to be accumulating in the area south of Arcas Reef.

Methods

Samples used in this study were collected from the Texas A&M University oceanographic research vessel *Hidalgo* during 1961 and 1962. Sediments were obtained with a Van Veen grab sampler. A subsample was removed for grain-size and constituent analysis, and the remaining part of the sample washed through a screen with 2–5 mm openings. Mollusks were removed from the coarse material remaining on the screen. Twenty-two samples having a large amount of coarse fraction were selected for the present study.

Prior to the grain-size analysis, the sediment subsample was dried at 60 degrees C. and weighed. It was then put into a jar of water containing the dispersant Calgon and

disaggregated on a shaking machine for about an hour. After disaggregation, the sample was washed on a 230 micron screen using a water spray to remove thoroughly the silt and clay fractions. The coarse fraction remaining on the screen was analyzed for grain-size distribution on a Ro-tap machine using 3-inch screens. The silt-clay fraction which passed through the 230 micron screen was analyzed by the pipette method. Prior to removing the first sample with a pipette, the silt-clay fraction in the 100 ml cylinder was agitated with a motorized stirrer.

Two samples (468, 470) had previously been analyzed for grain size distribution by Cann (1962) and Williams (1963). The amount of silt plus clay obtained in each analysis is compared below:

	Silt plus clay fraction %		
Sample number	This paper	Cann (1962)	Williams (1963)
468	48.6	42.8	2
470	47.1	48.2	16

The analyses reported here and by Cann are reasonably close, but both differ considerably from those of Williams. The reason for the difference is not clear, but possibly Williams did not wet-sieve the samples.

The general geographic distribution of mollusks listed in this paper was obtained principally from publications of Abbott (1954) and Warmke and Abbott (1961).

Depth Relationship of Mollusks

Variation of mollusk assemblages with depth has been recognized in many areas. Turbulence, temperature, salinity, light and bottom type change with water depth, making it difficult to assess the effect of a single variable on mollusk distribution. In a comprehensive study of the continental shelf of the northwestern Gulf of Mexico, Parker (1960) found the 1–12 fathom zone to have constantly turbulent isothermal water with bottom temperatures that reflected prevailing air temperatures. At 12–40 fathoms, turbulence and the difference between bottom temperatures in summer and winter were less. At 40–60 fathoms, bottom temperatures changed only slightly with season, and minimum temperatures were higher than minimum temperatures in the 1–12 fathom zone. From 60 to at least 250 fathoms, temperatures were virtually unchanged seasonally. Parker describes an assemblage of macro-invertebrates from the intermediate shelf (12–35 fathoms), outer shelf, 40–65 fathoms, and upper continental slope (65–600 fathoms).

On the Campeche Bank west of Alacran Reef, the 30 fathom curve is where the slope gradient changes, and therefore is a natural boundary for the division of the intermediate and outer parts of the continental shelf. Also, winter cooling seems to have its greatest effect in water shallower than 30 fathoms.

The upper edge of the continental slope is sharply defined on the western part of the bank at about 40 fathoms, but is less well defined along the northern edge at about 80 fathoms. The present investigation does not include samples from between depths of 55 and 92 fathoms. The boundary between the shelf and slope falls between these depths and is placed at 65 fathoms. Turbulence and seasonal temperature changes have little effect below this depth.

On the Campeche Bank the effect of depth on the distribution of species is readily apparent, but as most species have overlapping ranges it is difficult to designate a spe-

cific assemblage as having a particular depth range. As might be expected, adjacent depth zones have more species in common than widely separated zones. For example, 27 species collected from the intermediate shelf (15–30 fathoms) also occurred on the outer shelf (30–65 fathoms), but only 3 were collected on the upper slope (65–120 fathoms). Fourteen species were common to the outer shelf and upper slope.

The occurrence of more species-in-common in adjacent than in widely separated depth zones may be shown by use of the formula.[1]

$$\text{Species-in-common } \% = \frac{\text{number of species-in-common in any two samples x 100}}{\text{number of species in smaller sample}}$$

The above formula was applied to each sample from the intermediate and outer shelves and the results averaged. This was repeated for samples from the intermediate shelf and upper slope. and outer shelf and upper slope. The results are tabulated below:

Average per cent of species-in-common between depth zones

	outer shelf		upper slope
	30–40 fm	40–65 fm	65–120 fm
Intermediate shelf			
15–30 fm	21%	28%	2%
Outer shelf			
30–40 fm		35%	9%
40–60 fm			26%

The decrease in the number of species-in-common as depth zones become more widely separated is quite apparent from this table; for example. in the last column it is shown that the upper slope has 2 per cent species-in-common with the intermediate shelf, 9 per cent in-common with the inner part of the outer shelf, and 26 per cent in-common with the adjacent outer part of the outer shelf.

Results from use of the species-in-common formula also indicate that the composition of the mollusk assemblage becomes more uniform with depth. Each sample from the intermediate shelf. outer shelf. and upper slope is compared with every other sample within the same depth zone in the table below:

Depth zone	Average percentage of species-in-common
Intermediate shelf (15–30 fm)	20%
Outer shelf	
30–40 fm	24%
40–65 fm	42%
Upper slope (65–120 fm)	52%

This table shows that whereas the upper slope has 52 per cent species-in-common, the intermediate shelf has only 20 per cent. and the outer shelf has intermediate values of 24 and 42 per cent.

Some species and assemblages of species are commonly more abundant within certain depth limits and their presence therefore might be useful in estimating water depth if

[1] See Colbert. Edwin H. "The Mesozoic Tetrapods of South America," Amer. Mus. Nat. Hist. Bull., 1952. p. 237–258. for use of this formula with other organisms.

this were unknown. In general, these species do not occur in all samples within a depth zone, so that their absence is not as useful as their presence for estimating water depth.

Pelagic mollusks were in samples from depths of 39 to 92 fathoms and seem to be good indicators of the edge of the outer shelf (Table 1). Several species that occurred in fair abundance in three or more samples and might be good depth indicators in a Campeche Bank environment are listed in Table 2

Relationship Between Mollusks and Substrate

It is generally recognized that many benthonic organisms seem to prefer a particular type bottom or substrate. The distribution of gravel, sand, silt and clay in each sample in the present study is shown in histograms in Fig. 2. At station 520, three grab samples were obtained; the first and second contained algae but no sand, indicating a rock bottom; the third sample was composed of sediment with a high sand and gravel content. Remaining stations have small gravel fractions, and modes in either the sands, silt or clay size classes. In this paper the sediments are broadly classified as calcilutite if they contain more than 60 per cent silt and clay, and as calcarenite if they contain less than 60 per cent. (In part of this paper calcarenite has been referred to simply as sand, and calcilutite as lutite.)

Table 1

Distribution of pelagic mollusks

Sample No.	1272	470	468	1294	1336	1328
Depth fm	39	46	51	53	58	92
Species	Substrate	sand	sand	sand	sand	sand	lutite
Atlanta peroni		....	2[1]	8	2	4	....
Cavolina quadridentata		....	2	8	....	....	....
C. uncinata		8	....	10	19	....	....
C. longirostris		....	12	....	20	....	....
Styliola subula		....	....	....	1	....	....
Clio pyramidata		....	....	....	....	2	2

[1] Number of specimens picked from sample.

Table 2

Depth ranges of selected mollusks

Species	Depth range fm
Pyrunculus caelatus Bush	28 to 58
Nucula carpenteri Dall	51 to 120
Nucula crenulata A. Adams	92 to 120
Limopsis minuta Philippi	92 to 120
Limopsis sulcata Verrill and Bush	53 to 93
Chalmys nana Verrill and Bush	37 to 92
Lucina sombrerensis Dall	37 to 51
Phacoides muricatus Spengler	39 to 51
Microcardium tinctum Dall	30 to 42
Microcardium peramabile Dall	51 to 92
Gouldia cerina C. B. Adams	30 to 33
Phylloda squamifera Deshayes	25 to 46
Corbula sp.	24 to 37
Cardiomya perrostrata Dall	24 to 51
Arene variabilis Dall	42 to 120
Calyptraea centralis Conrad	23 to 46

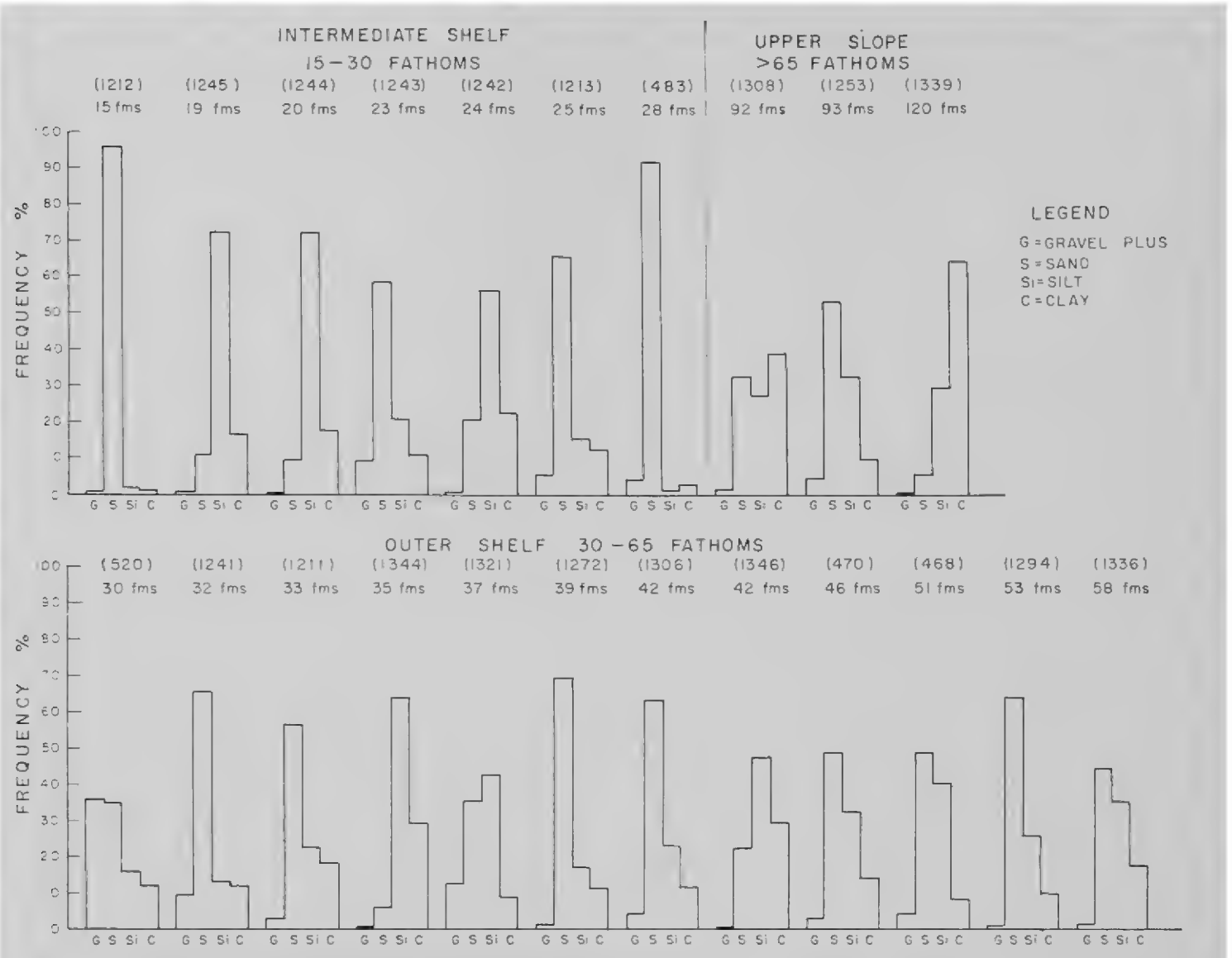

FIG. 2. Histograms showing distribution of size fractions in samples from which mollusks were studied.

The percentage of species common to both calcarenite and calcilutite samples was calculated by formula as 22 per cent. This is not greatly different from the percentage of species common to only calcarenite samples (28%), or to only calcilutite samples (29%). This suggests that in general the mollusk distribution was not greatly affected by substrate differences. On the other hand, the sample from station 520 which had more gravel than other samples and was close to a rock bottom contained 11 species of mollusks not found in other samples. It seems likely that this abundance of different species must be due, at least in part, to the substrate.

The sediment samples are comprised of 7 calcilutites and 15 calcarenites. If a random distribution of mollusks and sediment types is assumed, a species should on the average be present in twice as many calcarenites as calcilutites. The species listed in Table 3 are those which were found in calcarenites more times than would normally be expected. A list could not be made for species found mostly in calcilutites, because no species appeared in as many as three samples without at least one of them being a calcarenite.

AGE OF MOLLUKS

Because of the transgression of the sea after the last glacial stage of the Wisconsin, a question arises as to whether the mollusk shells collected from the Campeche Bank lived in the environment from which they were collected or are relicts of a lower sea level.

TABLE 3

List of mollusks found mostly in calcarenite

Species	Sediment type	
	Calcarenite	Calcilutite
Turritella acropora Dall	xxxx[1]	x
Epitonium novangliae Couthouy	xxxx	x
Amaea retifera Dall	xxx	..
Niso interrupta Sowerby	xxx	..
Calyptraea centralis Conrad	xxxxxx	..
Crucibulum sp.	xxxxxxx	xx
Nassarius cf. *albus* Say	xxxxxx	..
Marginella aureocincta Stearns	xxxxxx	x
Prunum virginianum Conrad	xxxxxxxx	..
Terebra protexta Conrad	xxxxx	x
Leptadrillia splendida Bartsch	xxxx	..
Ancistrosyrinx radiata Dall	xxxx	x
Drillia acestra Dall	xxx	..
Pyrunculus caelatus Bush	xxxxx	x
Nucula acuta Conrad	xxxxxxxx	xx
Lucina sombrerensis Dall	xxxx	..
Phacoides muricatus Spengler	xxxx	..
Microcardium tinctum Dall	xxxx	x
Phylloda squamifera Deshayes	xxxxx	..
Verticordia fischeriana Dall	xxxx	x
Poromya cf. *rostrata* Rehder	xxxx	..
Cuspidaria granulata Dall	xxx	..

[1] Eeach "x" indicates one sample containing the species.

Curray (1960, p. 254) lists C-14 dates obtained on mollusks from the continental shelf of the northwestern Gulf of Mexico along with the known depth ranges of the species dated. Species known to live along the shore line were selected by Curray in order to obtain the date when the sea stood at that level. Two species listed by Curray are *Strombus alatus* and *Architectonica nobilis*. Both species are listed as having a range of 1 to 10 fathoms on the shelf. On the Campeche Bank these species were collected in sample 1242 from a depth of 24 fathoms. A third species listed by Curray, *Aequipecten g. gibbus*, is assigned a range of 1 to 10 or possibly 30 fathoms. This species was collected from sample 1306 on the Campeche Bank at a depth of 42 fathoms. This suggests that samples 1242 and 1306 contain relict shells; however, it is possible that the three species have a wider depth range on the Campeche Bank than on the Louisiana-Texas shelf. It is also possible that the shells were transported from shallower water. Parker (1960, p. 335) lists both *Strombus alatus* and *Aequipecten g. gibbus* as being typical of the intermediate shelf at 12–40 fathoms off Texas and Louisiana, indicating that their depth range might be greater than listed by Curray (1960, p. 254).

Mollusks have been described from shallow waters of Alacran Reef (Rice and Kornicker, 1962), the northern coasts of Yucatan (Baker, 1891) and the Laguna de Terminos (Garcio-Cubas Jr., 1963). Table 4 lists mollusks collected both from these shallow water areas and from the deep water of the Campeche Bank. Although 13 species found in shallow water also occur in deeper parts of the Bank, there is no clear evidence that this is not due to their having a wide range rather than to the occurrence of relict forms on the shelf. *Nuculana acuta*, for example, is reported by Parker (1956, p. 347) from the deep shelf (13–50 fathoms) of the East Mississippi Delta, as well as from an enclosed lagoon (Parker, 1960, p. 310).

TABLE 4

Mollusks occurring in shallow and deep water in the Campeche Bank area

Water depth (fm) / Station number	15 1212	23 1243	25 1213	28 483	30 520	32 1241	39 1272	42 1306	42 1346	46 470	51 468	58 1336	92 1328	93 1253	120 1339
Olivella nivea[1]	--	--	--	x	--	x	--	--	x	--	--	--	--	--	--
Crepidula plana[1 2 3]	--	--	--	--	--	x	--	--	--	--	--	--	--	--	--
Balcis conoidea[2]	--	--	--	--	x	--	--	--	--	--	--	--	--	--	--
Acteon punctostriatus[2]	--	--	--	x	--	--	--	--	--	x	--	--	--	--	--
Retusa candei[2]	--	--	--	x	--	--	--	--	--	--	--	--	--	--	--
Nuculana acuta[2]	--	x	--	--	--	x	x	x	--	x	x	x	x	x	x
Emarginula phrixodes[3]	--	--	--	--	x	--	--	--	--	--	--	--	--	--	--
Diodora minuta[3]	x	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rissoina cancellata[3]	--	--	--	--	x	--	--	--	--	--	--	x	--	--	--
Glyphoturris quadrata[3]	--	--	--	--	--	--	--	--	--	--	--	x	--	--	--
Barbatia cancellaria[3]	x	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lima pellucida[3]	--	--	x	--	--	--	--	--	--	--	--	--	--	--	--
Codakia orbiculata[3]	x	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[1] Shallow water near Progreso (Baker, 1891)
[2] Laguna de Terminos (Garcia-Cubas Jr. 1963)
[3] Alacran Reef (Rice and Kornicker, 1962)

Although mollusks in the 22 samples studied give no positive evidence that they did not live in the environment from which they were collected, other factors such as the presence of oolites, which usually form in shallow water, in several samples (1241, 1253, 1294, 1321) suggests that some of the mollusks may be relicts of a lower sea level.

SPECIES LIST AND ENVIRONMENTAL DATA

Gastropoda

FISSURELLIDAE

Genus *Emarginula* Lamarck, 1801

Emarginula phrixodes Dall. Plate 1, Fig. 1. General distribution is eastern U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(2). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Emarginula pumila A. Adams. Plate 1, Fig. 2. General distribution is southeast Florida, Bermuda, West Indies to Brazil, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 520(2), 1339(1). Observed depth range on Campeche Bank in fathoms: 30–120. Bottom sediment at collecting sites: sand, lutite.

Genus *Diodora* Gray, 1821

Diodora cayenensis Lamarck . Plate 1, Fig. 3. General distribution is southeast U. S. to Brazil. Sample stations on Campeche Bank and number of specimens: 520(2), 1212(1). Observed depth range on Campeche Bank in fathoms: 15–30. Bottom sediment at collecting sites: sand.

Diodora minuta Lamarck. Plate 1, Fig. 4. General distribution is southeast Florida, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1212(3). Observed depth range on Campeche Bank in fathoms: 15. Bottom sendiment at collecting site: sand.

Genus *Rimula* Defrance, 1827

Rimula frenulata Dall. Plate 1, Fig. 5. General distribution is off North Carolina to east Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 520(2), 1339(1). Observed depth range on Campeche Bank in fathoms: 30–120. Bottom sediment at collecting sites: sand, lutite.

Genus *Hemitoma* Swainson, 1840

Hemitoma sp. Plate 1, Fig. 6. Sample station on Campeche Bank and number of specimens: 1212(1). Observed depth range on Campeche Bank in fathoms: 15. Bottom sediment at collecting site: sand.

TROCHIDAE

Genus *Solariella* Wood, 1842

Solariella lamellosa Verrill and Smith. Plate 1, Fig. 7. General distribution is Massachusetts to Key West, Yucatan, West Indies. Sample station on Campeche Bank and number of specimens: 1339(2). Observed depth range on Campeche Bank in fathoms: 120. Bottom sediment at collecting site: lutite.
Solariella sp. Plate 1, Fig. 8. Sample station on Campeche Bank and number of specimens: 1241(1). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

Genus *Calliostoma* Swainson, 1840

Calliostoma cf. *corbis* Dall. Plate 1, Fig. 9. Sample station on Campeche Bank and number of specimens: 1328(4). Observed depth range on Campeche Bank in fathoms: 92. Bottom sediment at collecting site: lutite.
Calliostoma cf. *fascinans* Schwengel and McGinty. Plate 1, Fig. 10. Sample station on Campeche Bank and number of specimens: 1346(1). Observed depth range on Campeche Bank in fathoms: 42. Bottom sediment at collecting site: lutite.

TURBINIDAE

Genus *Arene* H. and A. Adams, 1854

Arene variabilis Dall. Plate 1, Fig. 11. General distribution is North Carolina to southeast Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1294(2), 1306(1), 1336(32), 1339(2). Observed depth range on Campeche Bank in fathoms: 42–120. Bottom sediment at collecting sites: sand, lutite.
Arene tricarinata Stearns. Plate 1, Fig. 12. Sample station on Campeche Bank and number of specimens: 483(1). Observed depth range on Campeche Bank in fathoms: 27.7. Bottom sediment at collecting site: sand.

Genus *Mecoliotia* Hedley 1899

Mecoliotia sp. Plate 1, Fig. 13. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Genus unidentified

Sp. "A" Plate 1, Fig. 14. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

RISSOIDAE

Genus *Rissoina* Orbigny, 1840

Rissoina decussata Montagu. Plate 1, Fig. 15. General distribution is North Carolina to Lesser Antilles, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 1272(1), 1336(1), 1344(1), 1346(2). Observed depth range on Campeche Bank in fathoms: 35–58. Bottom sediment at collecting sites: sand, lutite.
Rissoina cancellata Philippi. Plate 1, Fig. 16. General distribution is southeast Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 520(11), 1336(5). Observed depth range on Campeche Bank in fathoms: 30–58. Bottom sediment at collecting sites: sand.
Rissoina fischeri Desjardin. Plate 1, Fig. 17. General distribution is Cuba, Puerto Rico, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(2). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

VITRINELLIDAE

Genus *Vitrinella* C. B. Adams, 1850

Vitrinella sp. Plate 1, Figs. 18, 19. Sample station on Campeche Bank and number of specimens: 520(4). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Genus *Episcynia* Mörch, 1875

Episcynia inornata Orbigny. Plate 1, Fig. 20. General distribution is Greater Antilles, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 520(1), 1346(1). Observed depth range on Campeche Bank in fathoms: 30–42. Bottom sediment at collecting sites: sand, lutite.

TURRITELLIDAE

Genus *Turritella* Lamarck, 1799

Turritella exoleta Linne. Plate 2, Fig. 1. General distribution is south half of Florida and West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1211(3), 1242(3), 1243(2), 1336(9), 1344(2). Observed depth range on Campeche Bank in fathoms: 24–58. Bottom sediment at collecting sites: sand, lutite.
Turritella acropora Dall. Plate 2, Fig. 2. General distribution is North Carolina to Florida, Texas, West Indies, Campeche Bank. Sample stations at Campeche Bank and number of specimens: 520(1), 1241(1), 1294(3), 1306(3), 1346(3). Observed depth range on Campeche Bank in fathoms: 30–53. Bottom sediment at collecting sites: sand, lutite.

ARCHITECTONICIDAE

Genus *Philippia* Gray, 1847

Philippia kresbi Mörch. Plate 2, Fig. 3. General distribution is southeast U. S. to West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1306(1). Observed depth range on Campeche Bank in fathoms: 42. Bottom sediment at collecting site: sand.

Genus *Architectonica* Röding, 1798

Architectonica nobilis Röding. Plate 2, Figs. 4, 5. General distribution is southeast U. S. to West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1242(1). Observed depth range on Campeche Bank in fathoms: 24. Bottom sediment at collecting site: lutite.

Genus *Spirolaxis* Monterosato, 1913

Spirolaxis exquisita Dall and Simpson. Plate 2, Fig. 6. General distribution is Jamaica, Cuba, Puerto Rico, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(2), 1336(1). Observed depth range on Campeche Bank in fathoms: 46–58. Bottom sediment at collecting sites: sand.

CERITHIIDAE

Genus *Alabina* Dall, 1902

Alabina cerithidioides Dall. Plate 2, Fig. 7. General distribution is Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(1), 520(5). Observed depth range on Campeche Bank in fathoms: 30–46. Bottom sediment at collecting sites: sand.

Genus *Cerithiopsis* Forbes and Hanley, 1851

Cerithiopsis abrupta Dall. Plate 2, Fig. 8. Sample station on Campeche Bank and number of specimens: 520(5). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Cerithiopsis crystallina Dall. Plate 2, Fig. 9. Sample station on Campeche Bank and number of specimens: 1253(1). Observed depth range on Campeche Bank in fathoms: 92. Bottom sediment at collecting site: sand.

Cerithiopsis greeni C. B. Adams. Plate 2, Fig. 10. General distribution is Cape Cod to Florida, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(3). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Cerithiopsis emersoni C. B. Adams. Plate 2, Fig. 11. General distribution is Massachusetts to West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(4). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Cerithiopsis sp. Plate 2, Fig. 12. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

TRIPHORIDAE

Genus *Triphora* Blainville, 1828

Triphora melanura C. B. Adams. Plate 2, Fig. 13. General distribution is West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(4). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Triphora sp. "A" Plate 2, Fig. 14. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Triphora sp. "B" Plate 2, Fig. 15. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Triphora sp. "C" Plate 2, Fig. 16. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Triphora sp. "D" Plate 2, Fig. 17. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Triphora sp. "E" Plate 3, Fig. 1. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Triphora sp. "F" Plate 3, Fig. 2. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Triphora sp. "G" Sample station on Campeche Bank and number of specimens: 1346(1). Observed depth range on Campeche Bank in fathoms: 42. Bottom sediment at collecting site: lutite.

EPITONIIDAE

Genus *Epitonium* Röding, 1798

Epitonium novangliae Couthouy. Plate 3, Fig. 3. General distribution is Massachusetts south to Brazil. Sample stations on Campeche Bank and number of specimens: 520(1), 1306(1), 1321(1), 1336(1), 1344(2). Observed depth range on Campeche Bank in fathoms: 30–58. Bottom sediment at collecting sites: sand, lutite.

Genus *Amaea* H. and A. Adams, 1853

Amaea retifera Dall. Plate 3, Fig. 4. General distribution is southeast U. S. and West Indies to Barbados, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 470(1), 520(1). Observed depth range on Campeche Bank in fathoms: 30–51. Bottom sediment at collecting sites: sand.

Genus *Opalia* H. and A. Adams, 1853

Opalia pumilio Mörch. Plate 3, Fig. 5. General distribution is southeast U. S. and West Indies, Campeche Bank. Sample station on Campeche Bank and number of species:

520(1). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

HIPPONICIDAE

Genus *Hipponix* Defrance, 1819

Hipponix sp. Plate 3, Fig. 6. Sample stations on Campeche Bank and number of specimens: 1243(1), 1328(2), 1336(1). Observed depth range on Campeche Bank in fathoms: 23–92. Bottom sediment at collecting sites: sand, lutite.

EULIMIDAE

Genus *Eulima* Risso, 1826

Eulima bifasciata Orbigny. Plate 3, Fig. 7. Sample stations on Campeche Bank and number of specimens: 470(1), 520(4), 1241(1), 1346(1). Observed depth range on Campache Bank in fathoms: 30–46. Bottom sediment at collecting sites: sand, lutite.

Genus *Niso* Risso, 1826

Niso interrupta Sowerby. Plate 3, Fig. 8. Sample stations on Campeche Bank and number of specimens: 468(2), 470(2), 1241(2). Observed depth range on Campeche Bank in fathoms: 32–51. Bottom sediment at collecting sites: sand.

Genus *Balcis* Leach, 1847

Eulima conoidea Kurtz and Stimpson. Plate 3, Fig. 9. General distribution is Florida and West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(5). Observed depth range on Campeche Bank in fathoms: 31. Bottom sediment at collecting site: sand.

FOSSARIDAE

Genus *Iselica* Dall, 1918

Iselica anomala C. B. Adams. Plate 3, Fig. 10. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 31. Bottom sediment at collecting site: sand.

CALYPTRAEIDAE

Genus *Calyptraea* Lamarck, 1799

Calyptraea centralis Conrad. Plate 3, Figs. 11, 12. General distribution is North Carolina to Texas, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(2), 520(13), 1211(2), 1213(1), 1241(2), 1243(1). Observed depth range on Campeche Bank in fathoms: 23–46. Bottom sediment at collecting sites: sand.

Genus *Crepidula* Lamarck, 1799

Crepidula plana Say. Plate 3, Figs. 13, 14. General distribution is eastern U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens:

1241(1). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

Genus *Crucibulum* Schumacher, 1817

Crucibulum auricula Gmelin. Plate 4, Figs. 1, 2. General distribution is west Florida to West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1306(1). Observed depth range on Campeche Bank in fathoms: 42. Bottom sediment at collecting site: sand.
Crucibulum sp. Plate 4, Figs. 3, 4. Sample stations on Campeche Bank and number of specimens: 470(1), 483(1), 1211(1), 1213(1), 1241(3), 1242(2), 1294(1), 1321(1), 1336(1), 1346(2). Observed depth range on Campeche Bank in fathoms: 24–58. Bottom sediment at collecting sites: sand, lutite.

XENOPHORIDAE

Genus *Xenophora* G. Fischer, 1807

Xenophora sp. Plate 4, Fig. 5. Sample station on Campeche Bank and number of specimens: 1328(1). Observed depth range on Campeche Bank in fathoms: 92. Bottom sediment at collecting site: lutite.

STROMBIDAE

Genus *Strombus* Linné, 1758

Strombus alatus Gmelin. Plate 4, Fig. 6. General distribution is South Carolina to both sides of Florida and to Texas, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1242(1). Observed depth range on Campeche Bank in fathoms: 24. Bottom sediment at collecting site: lutite.

ERATOIDAE

Genus *Trivia* Broderip, 1837

Trivia antillarum Schilder. Plate 4, Fig. 7. General distribution is southeast Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1241(1), 1294(1). Observed depth range on Campeche Bank in fathoms: 32–53. Bottom sediment at collecting sites: sand.
Trivia cf. *candidula* Gaskoin. Plate 4, Fig. 8. General distribution is North Carolina to southeast Florida to Barbados. Sample station on Campeche Bank and number of specimens: 1336(1). Observed depth range on Campeche Bank in fathoms: 58. Bottom sediment at collecting site: sand.

ATLANTIDAE

Genus *Atlanta* Lesueur, 1817

Atlanta peroni Lesueur. Plate 4, Figs. 9, 10. General distribution is Atlantic and Pacific warm water, Campeche Bank. Sample stations on Campeche Bank and number of spec-

imens: 468(8), 470(2), 1294(2), 1336(4). Observed depth range on Campeche Bank in fathoms: 46–58. Bottom sediment at collecting sites: sand.

NATICIDAE

Genus *Natica* Scopoli, 1777

Natica cf. *menkeana* Philippi. Plate 4, Fig. 11. General distribution is West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1328(1). Observed depth range on Campeche Bank in fathoms: 92. Bottom sediment at collecting site: lutite.

Genus *Sinum* Röding, 1798

Sinum sp. Plate 4, Fig. 12. Sample stations on Campeche Bank and number of specimens: 1306(1), 1336(9). Observed depth range on Campeche Bank in fathoms: 42–58. Bottom sediment at collecting sites: sand.

Genus *Stigmaulax* Mörch, 1852

Stigmaulax sulcata Born. Plate, 5, Fig. 1. General distribution is West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1242(1). Observed depth range on Campeche Bank in fathoms: 24. Bottom sediment at collecting site: lutite.

CYMATIIDAE

Genus *Distorsio* Röding, 1798

Distorsio clathrata Lamarck. Plate 5, Fig. 2. General distribution is North Carolina to Florida, Gulf states and Caribbean, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1336(2). Observed depth range on Campeche Bank in fathoms: 58. Bottom sediment at collecting site: sand.

MURICIDAE

Genus *Murex* Linné, 1758

Murex cabriti Bernardi. Plate 5, Fig. 3. General distribution is southern three-fourths of Florida, Lesser Antilles, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(4), 1241(3), 1242(1), 1272(1), 1306(10), 1321(2), 1344(1), 1346(2). Observed depth range on Campeche Bank in fathoms: 24–46. Bottom sediment at collecting sites: sand, lutite.

Murex pazi Crosse. Plate 5, Fig. 4. Sample stations on Campeche Bank and number of specimens: 1253(1), 1339(2). Observed depth range on Campeche Bank in fathoms: 93–120. Bottom sediment at collecting sites: sand, lutite.

Genus *Muricopsis* Bucquoy, Dautzenberg and Dollfus, 1882

Muricopsis oxytatus M. Smith. Plate 5, Fig. 5. General distribution is Florida Keys, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens:

1211(1). Observed depth range on Campeche Bank in fathoms: 33. Bottom sediment at collecting site: sand.

BUCCINIDAE

Genus *Antillophos* Woodring, 1928

Antillophos sp. Plate 5, Fig. 6. Sample stations on Campeche Bank and number of specimens: 468(2), 470(2), 1211(3), 1306(1), 1336(14), 1339(2), 1344(1), 1346(1). Observed depth range on Campeche Bank in fathoms: 33–120. Bottom sediment at collecting sites: sand, lutite.
Antillophos candei Orbigny. Plate 5, Fig. 7. General distribution is southeast U.S. to West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1336(1). Observed depth range on Campeche Bank in fathoms: 58. Bottom sediment at collecting site: sand.

Genus *Engoniophos* Woodring, 1928

Engoniophos sp. Plate 5, Fig. 8. Sample station on Campeche Bank and number of specimens: 1241(6). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

NASSARIIDAE

Genus *Nassarius* Duméril, 1806

Nassarius cf. *albus* Say. Plate 5, Fig. 9. Sample stations on Campeche Bank and number of specimens: 468(4), 1213(1), 1272(1), 1294(2), 1306(10), 1321(2). Observed depth range on Campeche Bank in fathoms: 25–53. Bottom sediment at collecting sites: sand.
Nassarius sp. Plate 5, Fig. 10. Sample station on Campeche Bank and number of specimens: 1241(1). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

OLIVIDAE

Genus *Olivella* Swainson, 1831

Olivella sp. "A" Plate 5, Fig. 11. Sample stations on Campeche Bank and number of specimens: 470(4), 1306(4). Observed depth range on Campeche Bank in fathoms: 42–46. Bottom sediment at collecting sites: sand.
Olivella sp. "B" Plate 5, Fig. 12. Sample stations on Campeche Bank and number of specimens: 470(1), 1243(1). Observed depth range on Campeche Bank in fathoms: 23–46. Bottom sediment at collecting sites: sand.
Olivella sp. "C" Plate 5, Fig. 13. Sample station on Campeche Bank and number of specimens: 1294(2). Observed depth range on Campeche Bank in fathoms: 52. Bottom sediment at collecting site: sand.
Olivella sp. "D" Plate 5, Fig. 14. Sample stations on Campeche Bank and number of specimens: 1321(4), 1328(12), 1336(3), 1339(3), 1344(4). Observed depth range on Campeche Bank in fathoms: 37–120. Bottom sediment at collecting sites: sand, lutite.
Olivella cf. *nivea* Gmelin. Plate 5, Fig. 15. General distribution is southeast Florida, West

Indies, Bermuda, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 483(1), 1241(6), 1346(4). Observed depth range on Campeche Bank in fathoms: 27.7–42. Bottom sediment at collecting sites: sand, lutite.

MITRIDAE

Genus *Mitra* Lamarck, 1799

Mitra nodulosa Gmelin. Plate 6, Fig. 1. General distribution is southeast U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(2). Observed depth range on Campeche Bank in fathoms: 31. Bottom sediment at collecting site: sand.

Mitra styria Dall. Plate 6, Fig. 2. General distribution is lower Florida Keys, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1328(1). Observed depth range on Campeche Bank in fathoms: 92. Bottom sediment at collecting site: lutite.

CANCELLARIIDAE

Genus *Cancellaria* Lamarck, 1799

Cancellaria smithii Dall. Plate 6, Fig. 3. Sample station on Campeche Bank and number of specimens: 1241(1). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

MARGINELLIDAE

Genus *Marginella* Lamarck, 1799

Marginella aureocincta Stearns. Plate 6, Fig. 4. General distribution is North Carolina to both sides of Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(2), 470(14), 483(2), 520(4), 1272(1), 1336(4), 1346(5). Observed depth range on Campeche Bank in fathoms: 27.7–58. Bottom sediment at collecting sites: sand, lutite.

Genuus *Prunum* Herrmannsen, 1852

Prunum sp. Plate 6, Fig. 5. Sample stations on Campeche Bank and number of specimens: 468(1), 1306(2), 1211(1). Observed depth range on Campeche Bank in fathoms: 33–51. Bottom sediment at collecting sites: sand.

Prunum virginianum Conrad. Plate 6, Fig. 6. General distribution is North Carolina to west Florida and Yucatan. Sample stations on Campeche Bank and number of specimens: 468(3), 470(2), 483(1), 520(1), 1272(5), 1294(2), 1306(5), 1321(4). Observed depth range on Campeche Bank in fathoms: 27.7–53. Bottom sediment at collecting sites: sand.

Prunum cf. *amabile* Redfield. Plate 6, Fig. 7. General distribution is off North Carolina to Key West, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1294(1). Observed depth range on Campeche Bank in fathoms: 53. Bottom sediment at collecting site: sand.

Prunum labiatum Kiener. Plate 6, Fig. 8. Sample station on Campeche Bank and number of specimens: 1346(1). Observed depth range on Campeche Bank in fathoms: 42. Bottom sediment at collecting site: sand, lutite.

CONIDAE

Genus *Conus* Linné, 1758

Conus austini Rehder and Abbott. Plate 6, Fig. 9. General distribution is Tortugas to Yucatan and West Indies. Sample station on Campeche Bank and number of specimens: 1336(1). Observed depth range on Campeche Bank in fathoms: 58. Bottom sediment at collecting site: sand.

TEREBRIDAE

Genus *Terebra* Bruguière, 1789

Terebra protexta Conrad. Plate 6, Fig. 10. General distribution is North Carolina to Texas, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1213(1), 1241(1), 1242(4), 1306(3), 1336(1), 1346(1). Observed depth range on Campeche Bank in fathoms: 20–58. Bottom sediment at collecting sites: sand, lutite.

Terebra concava Say. Plate 6, Fig. 11. General distribution is North Carolina to both sides of Florida, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1242(2). Observed depth range on Campeche Bank in fathoms: 24. Bottom sediment at collecting site: lutite.

Terebra limatula Dall. Plate 6, Fig. 12. General distribution is Puerto Rico, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1253(1), 1328(1), 1336(11). Observed depth range on Campeche Bank in fathoms: 58–93. Bottom sediment at collecting sites: sand, lutite.

Terebra sp. Plate 6, Fig. 13. Sample station on Campeche Bank and number of specimens: 1242(3). Observed depth range on Campeche Bank in fathoms: 24. Bottom sediment at collecting site: lutite.

Terebra cf. *floridana* Dall. Plate 6, Fig. 14. General distribution is off South Carolina to south Florida, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 1294(1). Observed depth range on Campeche Bank in fathoms: 51–53. Bottom sediment at collecting sites: sand.

TURRIDAE

Genus *Pyrgocythara* Woodring, 1928

Pyrgocythara coxi Fargo. Plate 6, Fig. 15. General distribution is Florida, Puerto Rico, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(1), 520(12). Observed depth range on Campeche Bank in fathoms: 30–46. Bottom sediment at collecting sites: sand.

Pyrocythara sp. Plate 6, Fig. 16. Sample station on Campeche Bank and number of specimens: 520(2). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Genus *Leptadrillia* Woodring, 1928

Leptadrillia splendida Bartsch. Plate 7, Fig. 1. General distribution is West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 470(1), 520(4), 1336(4). Observed depth range on Campeche Bank in fathoms: 30–58. Bottom sediment at collecting sites: sand.

Genus *Ancistrosyrinx* Dall, 1881

Ancistrosyrinx radiata Dall. Plate 2, Fig. 2. General distribution is south Florida, Gulf of Mexico, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(2), 470(1), 1306(1), 1336(1), 1339(1). Observed depth range on Campeche Bank in fathoms: 42–120. Bottom sediment at collecting sites: sand, lutite.

Genus *Polystira* Woodring, 1928

Polystira florencae Bartsch. Plate 7, Fig. 3. General distribution is Puerto Rico, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1211(1), 1242(1), 1294(1), 1336(5), 1346(1). Observed depth range on Campeche Bank in fathoms: 24–58. Bottom sediment at collecting sites: sand, lutite.

Genus *Crassispira* Swainson, 1840

Crassispira fuscescens Reeve. Plate 7, Fig. 4. General distribution is Florida Keys to West Indies. Sample stations on Campeche Bank and number of specimens: 1241(1), 1242(1). Observed depth range on Campeche Bank in fathoms: 24–32. Bottom sediment at collecting sites: sand, lutite.

Drillia acestra Dall. Plate 7, Fig. 5. Sample stations on Campeche Bank and number of specimens: 1211(1), 1241(2), 1336(1). Observed depth range on Campeche Bank in fathoms: 32–58. Bottom sediment at collecting sites: sand.

Genus *Daphnella* Hinds, 1844

Daphnella stegeri McGinty. Plate 7, Fig. 6. General distribution is Florida, Puerto Rico, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1213(1). Observed depth range on Campeche Bank in fathoms: 25. Bottom sediment at collecting site: sand.

Daphnella lymneiformis Kiener. Plate 7, Fig. 7. General distribution is southeast Florida, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1344(1). Observed depth range on Campeche Bank in fathoms: 35. Bottom sediment at collecting site: lutite.

Daphnella sp. Plate 7, Fig. 8. Sample station on Campeche Bank and number of specimens: 1241(1). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

Genus *Mangelia* Risso, 1826

Mangelia bartletti Dall. Plate 7, Fig. 9. General distribution is south Florida, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(4). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Genus *Vitricythara* Fargo, 1953

Vitricythara metria Dall. Plate 7, Fig. 10. General distribution is West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(2). Observed depth range on Campeche Bank in fathoms: 30. Bottom sediment at collecting site: sand.

Genus *Ithycythara* Woodring, 1928

Ithcythara sp. Plate 7, Fig. 11. Sample stations on Campeche Bank and number of specimens: 520(13), 1344(4). Observed depth range on Campeche Bank in fathoms: 30–35. Bottom sediment at collecting sites: lutite.

Genus *Glyphoturris* Woodring, 1928

Glyphoturris quadrata rugirima Dall. Plate 7, Fig. 12. General distribution is Florida, West Indies, Campeche Bank. Sample station on Campeche Bank and number of species: 1336(1). Observed depth range on Campeche Bank in fathoms: 58. Bottom sediment at collecting site: sand.

Genus *Cythara*

Cythara cymella Dall. Plate 7, Fig. 13. Sample station on Campeche Bank and number of specimens: 1339(2). Observed depth range on Campeche Bank in fathoms: 120. Bottom sediment at collecting site: lutite.

GENUS UNIDENTIFIED

Sp. "A" Plate 7, Fig. 14. Sample stations on Campeche Bank and number of specimens: 1272(1), 1336(1), 1344(1). Observed depth range on Campeche Bank: 35–58. Bottom sediment at collecting sites: sand, lutite.

Sp. "B" Plate 7, Fig. 15. Sample stations on Campeche Bank and number of specimens: 1294(1), 1306(1), 1328(1), 1336(1). Observed depth range on Campeche Bank in fathoms: 42–92. Bottom sediment at collecting sites: sand, lutite.

Sp. "C" Plate 7, Fig. 16. Sample station on Campeche Bank and number of specimens: 1244(1). Observed depth range on Campeche Bank in fathoms: 20. Bottom sediment at collecting site: lutite.

Sp. "D" Plate 7, Fig. 17. Sample stations on Campeche Bank and number of specimens: 1241(1), 1336(1). Observed depth range on Campeche Bank in fathoms: 32–58. Bottom sediment at collecting sites: sand.

Sp. "E" Plate 7, Fig. 18. Sample stations on Campeche Bank and number of specimens: 1253(1), 1346(1). Observed depth range on Campeche Bank in fathoms: 43–93. Bottom sediment at collecting sites: sand, lutite.

Sp. "F" Plate 7, Fig. 19. Sample station on Campeche Bank and number of specimens: 1243(1). Observed depth range on Campeche Bank in fathoms: 23. Bottom sediment at collecting site: sand.

Sp. "G" Plate 8, Fig. 1. Sample station on Campeche Bank and number of specimens: 1241(1). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

Sp. "H" Plate 8, Fig. 2. Sample stations on Campeche Bank and number of specimens: 468(1), 1336(1). Observed depth range on Campeche Bank in fathoms: 51–58. Bottom sediment at collecting sites: sand.

Sp. "I" Plate 8, Fig. 3. Sample station on Campeche Bank and number of specimens: 1339(1). Observed depth range on Campeche Bank in fathoms: 120. Bottom sediment at collecting site: lutite.

Sp. "J" Plate 8, Fig. 4. Sample station on Campeche Bank and number of specimens: 1253(1). Observed depth range on Campeche Bank in fathoms: 93. Bottom sediment at collecting site: sand.
Sp. "K" Plate 8, Fig. 5. Sample station on Campeche Bank and number of specicens: 1241(1). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.
Sp. "L" Plate 8, Fig. 6. Sample station on Campeche Bank and number of specimens: 1213(1). Observed depth range on Campeche Bank in fathoms: 25. Bottom sediment at collecting site: sand.

ACTEONIDAE

Genus *Acteon* Montfort, 1810

Acteon punctostriatus C. B. Adams. Plate 8, Fig. 7. General distribution is Cape Cod to Gulf of Mexico, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(1), 483(1). Observed depth range on Campeche Bank in fathoms: 27.7–46. Bottom sediment at collecting sites: sand.

RINGICULIDAE

Genus *Ringicula* Deshayes, 1838

Ringicula semistriata Orbigny. Plate 8, Fig. 8. General distribution is North Carolina to southeast Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 470(2), 1336(1). Observed depth range on Campeche Bank in fathoms: 46–58. Bottom sediment at collecting sites: sand.

ATYIDAE

Genus *Atys* Montfort, 1810

Atys riiseana Mörch. Plate 8, Fig. 9. General distribution is Florida to Lesser Antilles, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 520(1). Observed depth range on Campeche Bank in fathoms: 30–51. Bottom sediment at collecting sites: sand.

RETUSIDAE

Genus *Retusa* Brown, 1827

Retusa candei Orbigny. Plate 8, Fig. 10. General distribution is West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 483(1). Observed depth range on Campeche Bank in fathoms: 27.7. Bottom sediment at collecting site: sand.

Genus *Pyrunculus* Pilsbry, 1894

Pyrunculus caelatus Bush. Plate 8, Fig. 11. General distribution is North Carolina to southeast Florida, Campeche Bank. Sample stations and number of specimens: 468(10), 470(15), 483(1), 520(14), 1336(1), 1346(1). Observed depth range on Campeche Bank in fathoms: 27.7–58. Bottom sediment at collecting sites: sand, lutite.

Genus *Rhizorus* Montfort, 1810

Rhizorus actus Orbigny. Plate 8, Fig. 12. General distribution is southeast U. S., West Indies, Mayaguez, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 470(1). Observed depth range on Campeche Bank: 46–51. Bottom sediment at collecting sites: sand.

ACTEOCINIDAE

Genus *Cylichna* Lovén, 1846

Cylichna sp. (?). Plate 8, Fig. 13. Sample station on Campeche Bank and number of specimens: 468(1). Observed depth range on Campeche Bank in fathoms: 51. Bottom sediment at collecting site: sand.

SCAPHANDRIDAE

Genus *Schaphander* Montfort, 1810

Scaphander watsoni Dall. Plate 8, Fig. 14. Sample stations on Campeche Bank and number of specimens: 468(12), 470(8), 1241(6), 1242(1), 1272(4), 1294(1), 1306(4), 1321(3), 1328(1), 1336(14), 1346(16). Observed depth range on Campeche Bank in fathoms: 24–92. Bottom sediment at collecting sites: sand, lutite.

PYRAMIDELLIDAE

Genus *Peristichia* Dall, 1889

Peristichia toreta Dall. Plate 8, Fig. 15. Sample stations on Campeche Bank and number of specimens: 1242(1). Observed depth range on Campeche Bank in fathoms: 24. Bottom sediment at collecting site: lutite.

CAVOLINIDAE

Genus *Cavolina* Abildgaard, 1791

Cavolina quadridentata Lesueur. Plate 8, Fig. 16. General distribution is worldwide. pelagic. Sample stations on Campeche Bank and number of specimens: 468(8), 470(2). Observed depth range on Campeche Bank in fathoms: 46–51. Bottom sediment at collecting sites: sand.

Cavolina uncinata Rang. Plate 8, Fig. 17. General distribution is Puerto Rico, Mayaguez, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(10), 1272(8), 1294(19). Observed depth range on Campeche Bank in fathoms: 39–53. Bottom sediment at collecting sites: sand.

Cavolina longirostris Lesueur. Plate 8, Fig. 18. General distribution is worldwide, pelagic. Sample stations on Campeche Bank and number of specimens: 468(12), 1294(20), 1336(1). Observed depth range on Campeche Bank in fathoms: 51–58. Bottom sediment at collecting sites: sand.

Cavolina sp. Plate 9, Fig. 1. Sample station on Campeche Bank and number of specimens: 1339(1). Observed depth range on Campeche Bank in fathoms: 120. Bottom sediment at collecting site: lutite.

Genus *Styliola* Lesueur, 1825

Styliola subula Quoy and Gaimard. Plate 9, Fig. 2. General distribution is Puerto Rico and Mayaguez, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1294(1). Observed depth range on Campeche Bank in fathoms: 53. Bottom sediment at collecting site: sand.

Genus *Clio* Linné, 1767

Clio pyramidata Linné. Plate 9, Fig. 3. General distribution is worldwide, pelagic. Sample stations on Campeche Bank and number of specimens: 1328(2), 1336(2). Observed depth range on Campeche Bank in fathoms: 58–92. Bottom sediment at collecting sites: lutite, sand.

SIPHONARIIDAE

Genus *Williamia* Monterosato, 1884

Williamia krebsi Mörch. Plate 9, Fig. 4. General distribution is Florida Keys, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(1). Observed depth range on Campeche Bank in fathoms: 31. Bottom sediment at collecting site: sand.

Scaphopoda

SIPHONODENTALIIDAE

Genus *Cadulus* Philippi, 1844

Cadulus quadridentatus Dall. Plate 9, Fig. 5. General distribution is southeast. U.S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 483(1). Observed depth range on Campeche Bank in fathoms: 27.7. Bottom sediment at collecting site: sand.

Cadulus sp. "A" Plate 9, Fig. 6. Sample station on Campeche Bank and number of specimens: 470(1). Observed depth range on Campeche Bank in fathoms: 46. Bottom sediment at collecting site: sand.

Cadulus sp. "B" Plate 9, Fig. 7. Sample station on Campeche Bank and number of specimens: 1294(1). Observed depth range on Campeche Bank in fathoms: 53. Bottom sediment at collecting site: sand.

Cadulus sp. "C" Plate 9, Fig. 8. Sample station on Campeche Bank and number of specimens: 1339(1). Observed depth range on Campeche Bank in fathoms: 120. Bottom sediment at collecting site: lutite.

DENTALIIDAE

Genus *Dentalium* Linné, 1758

Dentalium laqueatum Verrill. Plate 9, Fig. 9. General distribution is North Carolina to south Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 1294(1), 1336(1), 1346(1). Observed depth range on Campeche Bank in fathoms: 42–58. Bottom sediment at collecting sites: sand, lutite.

Dentalium sowerbyi Guilding. Plate 9, Fig. 10. General distribution is North Carolina, Texas to Florida, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 468(1). Observed depth range on Campeche Bank in fathoms: 51. Bottom sediment at collecting site: sand.
Dentalium sp. "A" Plate 9, Fig. 11. Sample stations on Campeche Bank and number of specimens: 1272(1), 1294(1). Observed depth range on Campeche Bank: 39–53. Bottom sediment at collecting site: sand.
Dentalium sp. "B" Plate 9, Fig. 12. Sample stations on Campeche Bank and number of specimens: 483(1), 520(3). Observed depth range on Campeche Bank in fathoms: 27.7–31. Bottom sediment at collecting sites: sand.
Dentalium sp. "C" Plate 9, Fig. 13. Sample stations on Campeche Bank and number of specimens: 1253(1), 1339(1). Observed depth range on Campeche Bank in fathoms: 93–120. Bottom sediment at collecting site: sand, lutite.
Dentalium sp. "D" Plate 9, Fig. 14. Sample stations on Campeche Bank and number of specimens: 1328(1), 1339(1). Observed depth range on Campeche Bank in fathoms: 92–120. Bottom sediment at collecting sites: lutite.

Pelecypoda

NUCULIDAE

Genus *Nucula* Lamarck, 1799

Nucula crenulata A. Adams. Plate 9, Figs. 15, 16. General distribution is South Carolina to Key West, Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1328(8), 1339(6). Observed depth range on Campeche Bank in fathoms: 92–120. Bottom sediment at collecting sites: lutite.

NUCULANIDAE

Genus *Nuculana* Link, 1807

Nuculana acuta Conrad. Plate 9, Figs. 17, 18. General distribution is Cape Cod to West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(2), 470(7), 1241(24), 1243(2), 1253(2), 1272(6), 1306(2), 1328(12), 1336(2), 1339(11). Observed depth range on Campeche Bank in fathoms: 23–120. Bottom sediment at collecting sites: sand, lutite.
Nuculana messanensis Seguenza. Plate 10, Figs. 1, 2. General distribution is Cape Cod to West Indies, Campeche Bank.Sample stations on Campeche Bank and number of specimens: 468(2), 470(2), 1242(21). Observed depth range on Campeche Bank in fathoms: 24–51. Bottom sediment at collecting sites: sand, lutite.
Nuculana carpenteri Dall. Plate 10, Figs. 3, 4. General distribution is North Carolina to West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(16), 1294(10), 1336(3), 1339(3). Observed depth range on Campeche Bank in fathoms: 51–120. Bottom sediment at collecting sites: sand, lutite.

ARCIDAE

Genus *Barbatia* Gray, 1847

Barbatia cancellaria Lamarck. Plate 10, Figs. 5, 6. General distribution is south Florida, West Indies, Campeche Bank. Sample station on Campeche Bank and number of speci-

mens: 1212(4). Observed depth range on Campeche Bank in fathoms: 15. Bottom sediment at collecting site: sand.

LIMOPSIDAE

Genus *Limopsis* Sasso, 1827

Limopsis minuta Philippi. Plate 10, Figs. 7, 8. General distribution is Newfoundland to both sides of Florida, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1253(2), 1328(6), 1339(47). Observed depth range on Campeche Bank in fathoms: 92–120. Bottom sediment at collecting sites: sand, lutite.
Limopsis sulcata Verrill and Bush. Plate 10, Figs. 9, 10. General distribution is Cape Cod to Florida, Gulf States, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(6), 1253(1), 1294(4), 1328(12). Observed depth range on Campeche Bank in fathoms: 51–93. Bottom sediment at collecting site: sand, lutite.

PLICATULIDAE

Genus *Plicatula* Lamarck, 1801

Plicatula gibbosa Lamarck. Plate 11, Fig. 1, 2. General distribution is southeast U. S., Gulf states, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 520(2). Observed depth range on Campeche Bank in fathoms: 31. Bottom sediment at collecting site: sand.

PECTINIDAE

Genus *Chlamys* Röding, 1798

Chlamys benedicti Verrill and Bush. Plate 11, Figs. 3, 4. General distribution is Florida, Gulf of Mexico, Puerto Rico, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(1), 1272(1). Observed depth range on Campeche Bank in fathoms: 39–46. Bottom sediment at collecting sites: sand.
Chlamys nana Verrill and Bush. Plate 11, Figs. 5, 6. General distribution is eastern U. S., Puerto Rico, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(6), 1306(13), 1321(3), 1328(4). Observed depth range on Campeche Bank in fathoms: 37–92. Bottom sediment at collecting sites: sand, lutite.

Genus *Aequipecten* P. Fischer, 1886

Aequipecten gibbus Linné. Plate 11, Figs. 7, 8. General distribution is eastern U. S., Gulf of Mexico, West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1306(3). Observed depth range on Campeche Bank in fathoms: 42. Bottom sediment at collecting site: sand.
Aequipecten muscosus Wood. Plate 11, Figs. 9, 10. General distribution is southeast U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1213(4). Observed depth range on Campeche Bank in fathoms: 25. Bottom sediment at collecting site: sand.

LIMIDAE

Genus *Lima* Bruguière, 1797

Lima pellucida C. B. Adams. Plate 11, Figs. 11, 12. General distribution is southeast U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1213(2). Observed depth range on Campeche Bank in fathoms: 25. Bottom sediment at collecting site: sand.

ASTARTIDAE

Genus *Astarte* Sowerby, 1816

Astarte nana Dall. Plate 12, Figs. 1, 2. General distribution is North Carolina to Florida, Gulf states, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(2), 1328(1), 1339(5). Observed depth range on Campeche Bank in fathoms: 51–120. Bottom sediment at collecting sites: sand, lutite.

CRASSATELLIDAE

Genus *Eucrassatella* Iredale, 1924

Eucrassatella speciosa A. Adams. Plate 12, Figs. 3, 4. General distribution is North Carolina to both sides of Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1211(1), 1241(3). Observed depth range on Campeche Bank in fathoms: 32–33. Bottom sediment at collecting sites: sand.

LUCINIDAE

Genus *Lucina* Bruguière, 1797

Lucina sombrerensis Dall. Plate 12, Figs. 5, 6. General distribution is southern Florida, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(13), 470(3), 1306(1), 1321(6). Observed depth range on Campeche Bank in fathoms: 37–51. Bottom sediment at collecting sites: sand.

Genus *Phacoides* Gray, 1847

Phacoides muricatus Spengler. Plate 12, Figs. 7, 8. General distribution is Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(8), 470(13), 1272(5), 1306(4). Observed depth range on Campeche Bank in fathoms: 39–51. Bottom sediment at collecting sites: sand.

Genus *Anodontia* Link, 1807

Anodontia alba Link. Plate 12, Figs. 9, 10. General distribution is southeast U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1211(2). Observed depth range on Campeche Bank in fathoms: 33. Bottom sediment at collecting site: sand.

Genus *Codakia* Scopoli, 1777

Codakia orbiculata Montagu. Plate 12, Figs. 11, 12. General distribution is southeast U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of

specimens: 1212(1). Observed depth range on Campeche Bank in fathoms: 15. Bottom sediment at collecting site: sand.

CARDIIDAE

Genus *Laevicardium* Swainson, 1840

Laevicardium pictum Ravenel. Plate 13, Figs. 1, 2. Southeast U. S., West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 483(2), 520(2). Observed depth range on Campeche Bank in fathoms: 27.7–31. Bottom sediment at collecting sites: sand.

Genus *Microcardium* Thiele, 1934

Microcardium tinctum Dall. Plate 13, Figs. 3, 4. Sample stations on Campeche Bank and number of specimens: 520(8), 1211(4), 1241(5), 1306(3), 1346(5). Observed depth range on Campeche Bank in fathoms: 31–42. Bottom sediment at collecting sites: sand, lutite.

Microcardium peramabile Dall. Plate 13, Figs. 5, 6. General distribution is Rhode Island to West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(1), 1294(2), 1328(5). Observed depth range on Campeche Bank in fathoms: 51–92. Bottom sediment at collecting sites: sand, lutite.

Genus *Americardia* Stewart, 1930

Americardia guppyi Thiele. Plate 14, Figs. 1. 2. General distribution is Florida, Bahamas, Caribbean, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1306(1). Observed depth range on Campeche Bank in fathoms: 42(1). Bottom sediment at collecting site: sand.

VENERIDAE

Genus *Chione* Muhlfeld, 1811

Chione cf. *paphia* Linné. Plate 13, Figs. 7, 8. General distribution is lower Florida Keys, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(2), 1241(2), 1244(1), 1245(1), 1344(2). Observed depth range on Campeche Bank in fathoms: 19–51. Bottom sediment at collecting sites: sand, lutite.

Genus *Gouldia* C. B. Adams, 1845

Gouldia cerina C. B. Adams. Plate 14, Figs. 3, 4. General distribution is southeast U. S., West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 520(2), 1211(6), 1241(9). Observed depth range on Campeche Bank in fathoms: 31–33. Bottom sediment at collecting sites: sand.

Gouldia insularis Dall and Simpson. Plate 14, Figs. 5, 6. General distribution is Puerto Rico, Campeche Bank. Sample station on Campeche Bank and number of Specimens: 520(5). Observed depth range on Campeche Bank in fathoms: 31. Bottom sediment at collecting site: sand.

Genus *Transennella* Dall, 1883

Transennella sp. Plate 14, Figs. 7, 8. Sample station on Campeche Bank and number of specimens: 483(2). Observed depth range on Campeche Bank in fathoms: 27.7. Bottom sediment at collecting site: sand.

Genus *Pitar* Römer, 1857

Pitar cf. *fulminata* Menke. Plate 14, Figs. 9, 10. General distribution is southeast U. S., West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 520(1), 1241(1), 1211(1). Observed depth range on Campeche Bank in fathoms: 31–33. Bottom sediment at collecting sites: sand.
Pitar sp. Plate 14, Figs. 11, 12. Sample station on Campeche Bank and number of specimens: 1344(1). Observed depth range on Campeche Bank in fathoms: 35. Bottom sediment at collecting site: lutite.

Genus *Antigona* Schumacher, 1817

Antigona sp. Plate 14. Figs. 13, 14. Sample station on Campeche Bank and number of specimens: 1211(1). Observed depth range on Campeche Bank in fathoms: 33. Bottom sediment at collecting site: sand.

TELLINIDAE

Genus *Tellina* Linné, 1758

Tellina aequistriata Say. Plate 15, Figs. 1, 2. General distribution is southeast U. S. to northern Brazil. Sample stations on Campeche Bank and number of specimens: 468(2), 470(1), 1242(2), 1244(2), 1245(1), 1306(2). Observed depth range on Campeche Bank in fathoms: 19–51. Bottom sediment at collecting sites: sand, lutite.
Tellina cf. *versicolor* DeKay. Plate 15, Fig. 3. General distribution is New York to south half of Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(2), 1243(2), 1244(2). Observed depth range on Campeche Bank in fathoms: 20–51. Bottom sediment at collecting sites: sand, lutite.

Genus *Phylloda* Schumacher, 1817

Phylloda squamifera Deshayes. Plate 15, Figs. 4, 5. General distribution is North Carolina to south half of Florida, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(2), 1213(1), 1241(5), 1272(4), 1306(4). Observed depth range on Campeche Bank in fathoms: 25–46. Bottom sediment at collecting sites: sand.

Genus *Macoma* Leach, 1819

Macoma tenta Say. Plate 15, Figs. 6, 7. General distribution is Cape Cod to Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(3), 1213(4), 1241(5), 1242(1), 1243(2), 1245(1), 1272(5), 1294(4), 1306(7), 1344(1), 1346(21). Observed depth range on Campeche Bank in fathoms: 19–46. Bottom sediment at collecting sites: sand, lutite.

SEMELIDAE

Genus *Semele* Schumacher, 1817

Semele bellastriata Conrad. Plate 15, Figs. 8, 9. General distribution is southeast U. S., West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1241(2). Observed depth range on Campeche Bank in fathoms: 32. Bottom sediment at collecting site: sand.

Genus *Solecurtus* Blainville, 1825

Solecurtus cumingianus Dunker. Plate 15, Figs. 10, 11. General distribution is southeast U. S., West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 1241(2), 1328(1). Observed depth range on Campeche Bank in fathoms: 32–92. Bottom sediment at collecting sites: sand, lutite.

CORBULIDAE

Genus *Corbula* Bruguière, 1792

Corbula sp. Plate 15, Fig. 12. Sample stations on Campeche Bank and number of specimens: 1242(5), 1244(1), 1321(25), 1344(16). Observed depth range on Campeche Bank in fathoms: 20–37. Bottom sediment at collecting sites: sand, lutite.

Genus *Notocorbula* Iredale, 1930

Notocorbula operculata Philippi. Plate 16, Figs. 1, 2. General distribution is southeast U. S., Gulf of Mexico, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 520(4), 1243(2). Observed depth range on Campeche Bank in Fathoms: 23–31. Bottom sediment at collecting sites: sand.

VERTICORDIIDAE

Genus *Verticordia* Sowerby, 1844

Verticordia ornata Orbigny. Plate 16. Figs. 3, 4. General distribution is eastern U. S., West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(10), 470(3). Observed depth range on Campeche Bank in fathoms: 46–51. Bottom sediment at collecting sites: sand.

Verticordia fischeriana Dall. Plate 16, Figs. 5, 6. General distribution is North Carolina to West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(3), 1306(3), 1321(2), 1336(3), 1339(1). Observed depth range on Campeche Bank in fathoms: 37–120. Bottom sediment at collecting sites: sand, lutite.

Verticordia sp. Plate 16, Figs. 7, 8. Sample station on Campeche Bank and number of specimens: 468(1). Observed depth range on Campeche Bank in fathoms: 51. Bottom sediment at collecting site: sand.

POROMYIDAE

Genus *Poromya* Forbes, 1844

Poromya cf. *rostrata* Rehder. Plate 16, Figs. 9, 10. Sample stations on Campeche Bank

and number of specimens: 468(2), 1272(3), 1306(4), 1321(2). Observed depth range on Campeche Bank in fathoms: 37–51. Bottom sediment at collecting sites: sand.

CUSPIDARIIDAE

Genus *Cuspidaria* Nardo, 1840

Cuspidaria granulata Dall. Plate 16, Figs. 11, 12. General distribution is off Miami, Florida, West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 470(1), 1241(2), 1306(2). Observed depth range on Campeche Bank in fathoms: 32–46. Bottom sediment at collecting sites: sand.
Cuspidaria cf. *jeffreysi* Dall. Plate 16, Figs. 13, 14. General distribution is south half of Florida, West Indies. Sample station on Campeche Bank and number of specimens: 1272(3). Observed depth range on Campeche Bank in fathoms: 39. Bottom sediment at collecting site: sand.

Genus *Cardiomya* A. Adams, 1864

Cardiomya perrostrata Dall. Plate 16, Fig. 15. General distribution is West Indies, Campeche Bank. Sample stations on Campeche Bank and number of specimens: 468(7), 1242(2), 1272(8). Observed depth range on Campeche Bank in fathoms: 24–51. Bottom sediment at collecting sites: sand, lutite.
Cardiomya ornatissima Orbigny. Plate 16, Fig. 16. General distribution is southeast U. S. to West Indies, Campeche Bank. Sample station on Campeche Bank and number of specimens: 1242(1). Observed depth range on Campeche Bank in fathoms: 24. Bottom sediment at collecting site: lutite.

Acknowledgments

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PLATE 1

1. *Emarginula phrixodes* Dall (×6)
2. *Emarginula pumila* A. Adams (×10)
3. *Diodora cayenensis* Lamarck (×4)
4. *Diodora minuta* Lamarck (×4)
5. *Rimula frenulata* Dall (×10)
6. *Hemitoma* sp. (×4)
7. *Solariella lamellosa* Verrill and Smith (×10)
8. *Solariella* sp. (×6)
9. *Calliostoma* cf. *corbis* Dall (×4)
10. *Calliostoma* cf. *fascinans* Schwengel and McGinty (×4)
11. *Arene variabilis* Dall (×4)
12. *Arene tricarinata* Stearns (×10)
13. *Mecoliotia* sp. (×15)
14. Unidentified sp. "A" (×15)
15. *Rissoina decussata* Montagu (×4)
16. *Rissoina cancellata* Philippi (×10)
17. *Rissoina fischeri* (×15)
18, 19. *Vitrinella* sp. (×10)
20. *Episcynia inornata* Orbigny (×10)

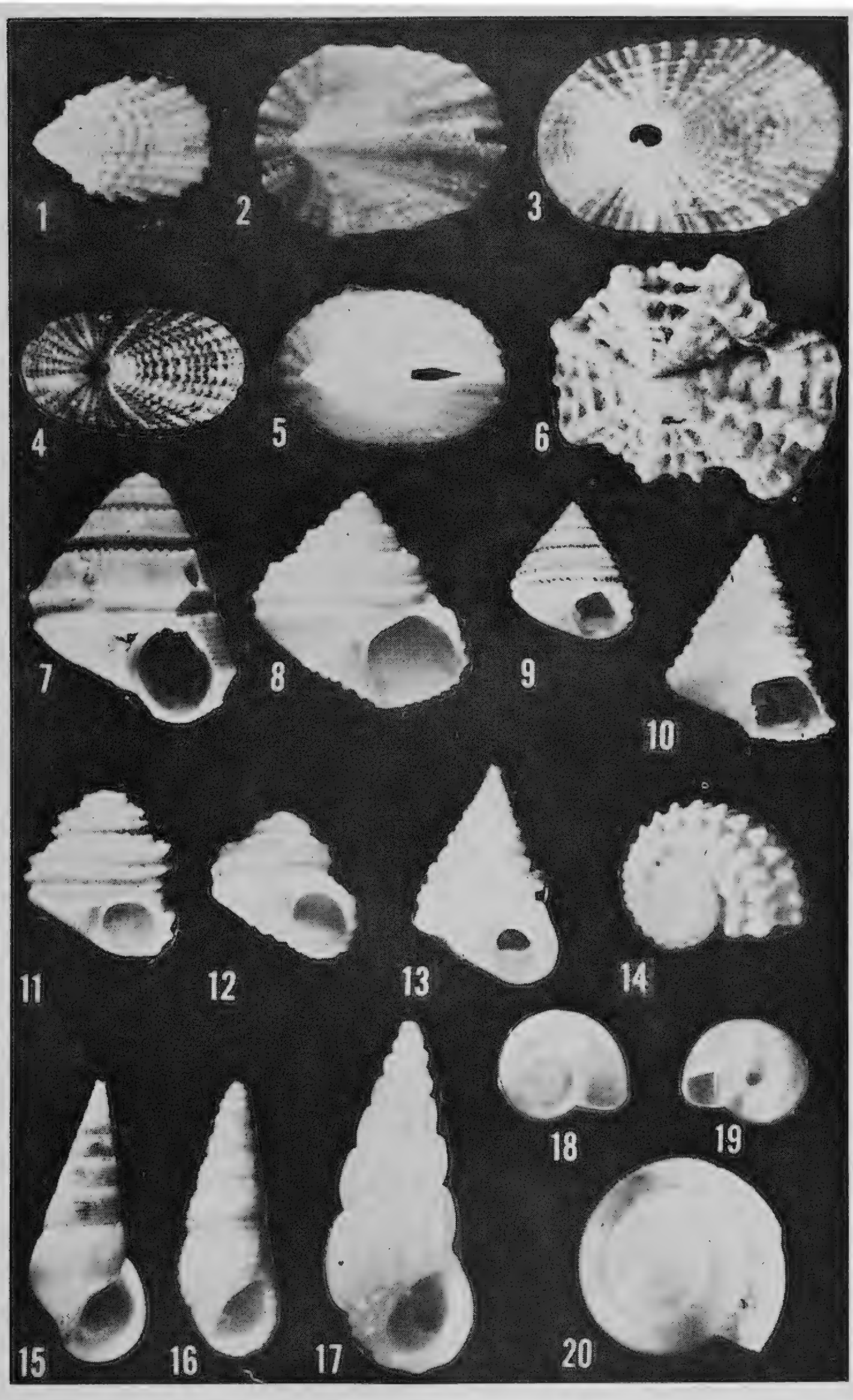
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PLATE 2

1. *Turritella exoleta* Linné (×4)
2. *Turritella acropora* Dall (×3)
3. *Philippia krebsi* Mörch (×6)
4, 5. *Architectonica nobilis* Röding (×2)
6. *Spirolaxis exquisita* Dall and Simpson (×10)
7. *Alabina cerithidioides* Dall (×15)
8. *Cerithiopsis abrupta* Dall (×15)
9. *Cerithiopsis crystallina* Dall (×4)
10. *Cerithiopsis greeni* C. B. Adams (×15)
11. *Cerithiopsis emersoni* C. B. Adams (×15)
12. *Cerithiopsis* sp. (×15)
13. *Triphora melanura* C. B. Adams (×15)
14. *Triphora* sp. "A" (×15)
15. *Triphora* sp. "B" (×15)
16. *Triphora* sp. "C" (×15)
17. *Triphora* sp. "D" (×15)

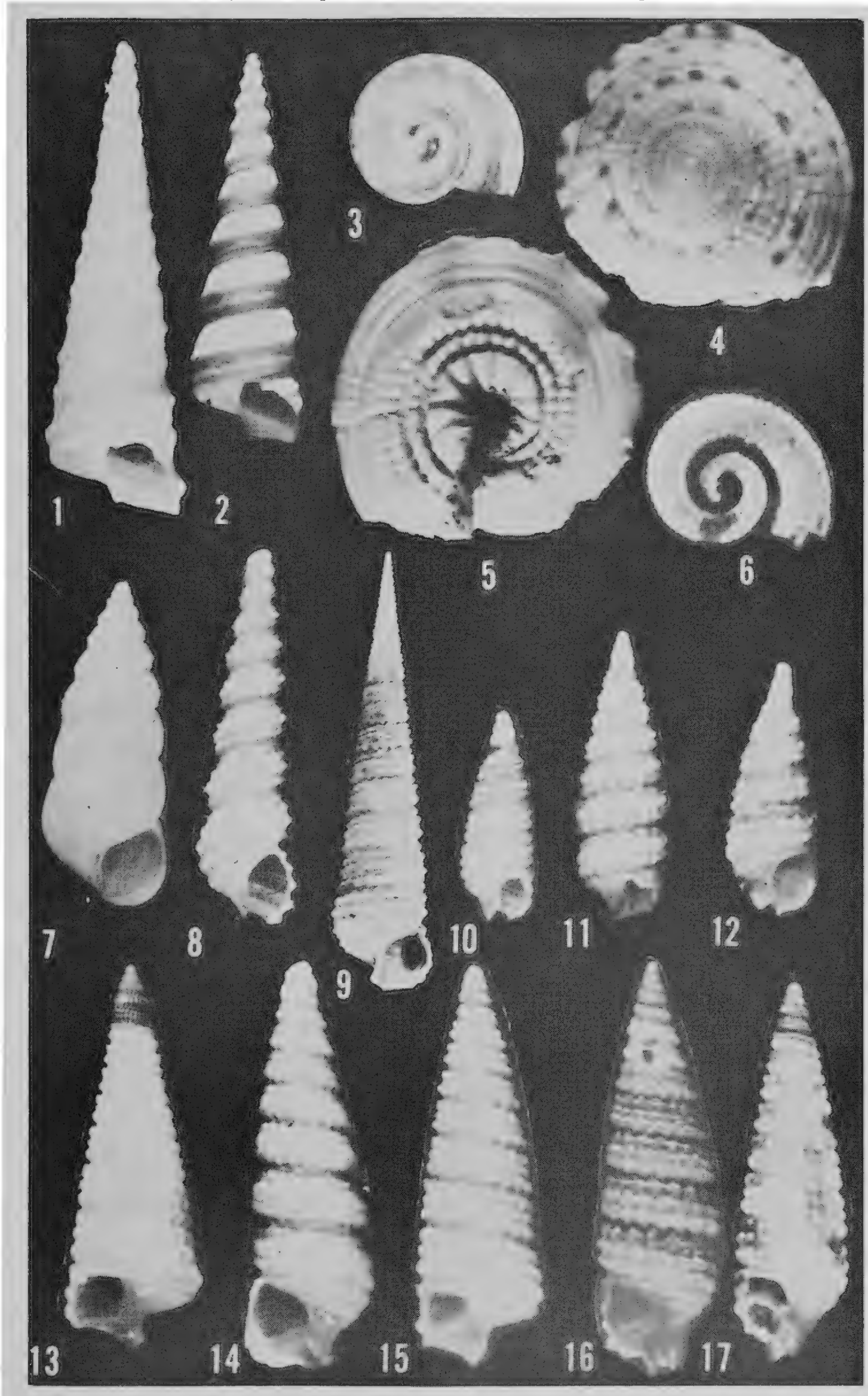
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Plate 3

1. *Triphora* sp. "E" (×15)
2. *Triphora* sp. "F" (×15)
3. *Epitonium novangliae* Couthouy (×6)
4. *Amaea retifera* Dall (×10)
5. *Opalia pumilio* Mörch (×15)
6. *Hipponix* sp. (×6)
7. *Eulima bifasciata* Orbigny (×6)
8. *Niso interrupta* Sowerby (×15)
9. *Balcis conoidea* Kurtz and Stimpson (×15)
10. *Iselica anomala* C. B. Adams (×15)
11, 12. *Calyptraea centralis* Conrad (×6)
13, 14. *Crepidula plana* Say (×4)

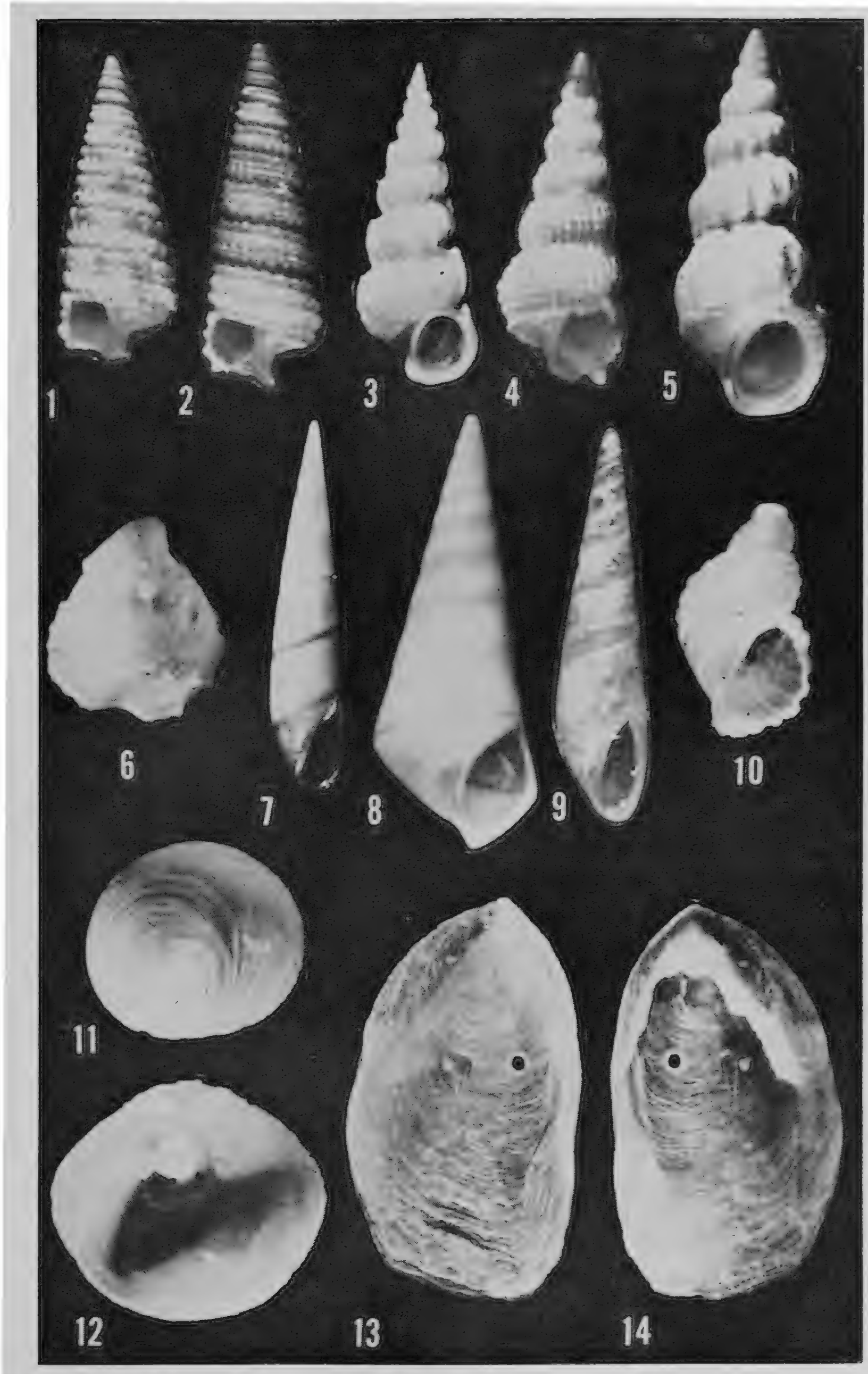
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PLATE 4

1, 2. *Crucibulum auricula* Gmelin (×4)
3, 4. *Crucibulum* sp. (×4)
5. *Xenophora* sp. (×6)
6. *Strombus alatus* Gmelin (×¾)
7. *Trivia antillarum* Schilder (×6)
8. *Trivia* cf. *candidula* Gaskoin (×6)
9, 10. *Atlanta peroni* Lesueur (×10)
11. *Natica cf. menkeana* Philippi (×3)
12. *Sinum* sp. (×6)

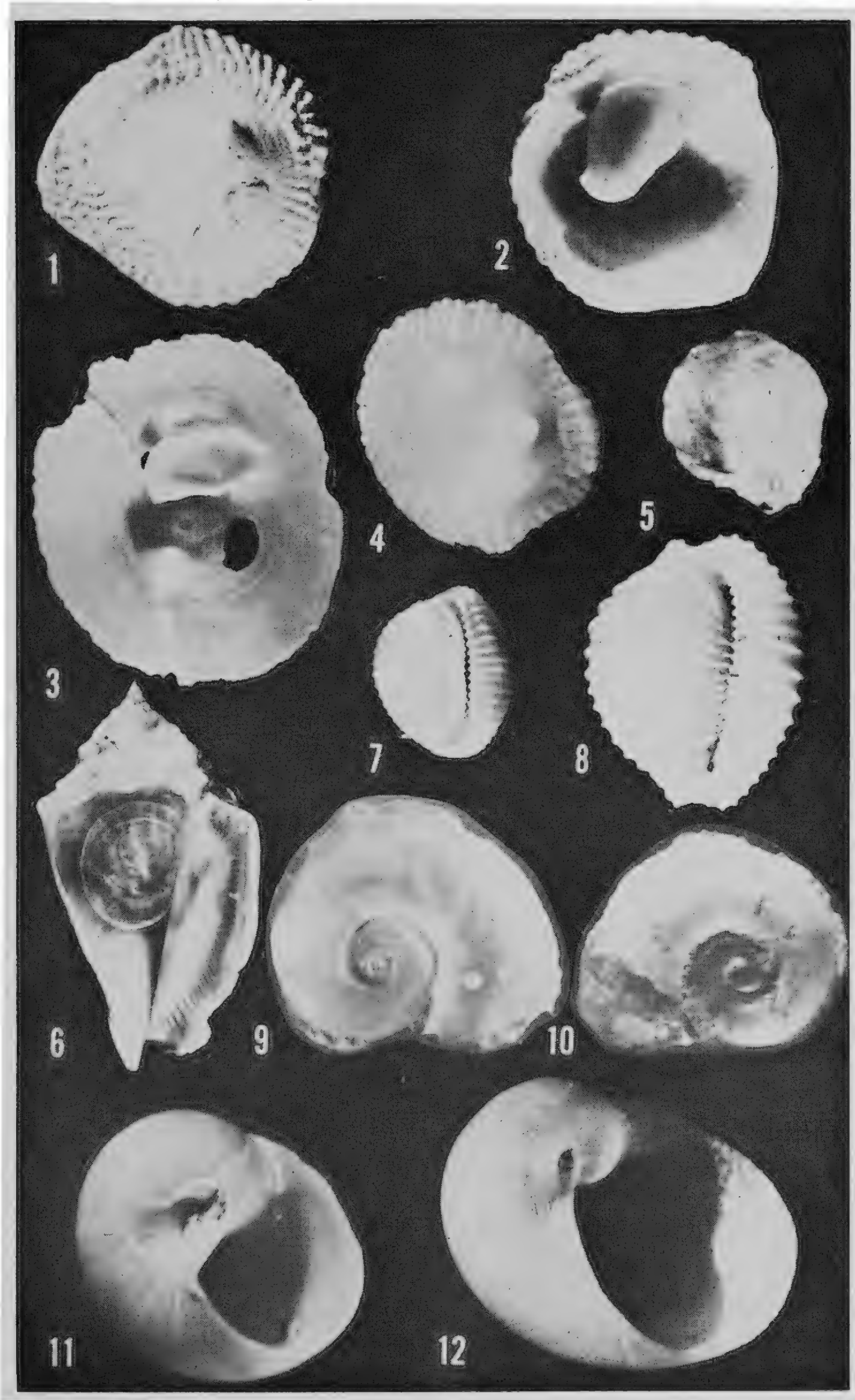
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Plate 5

1. *Stigmaulax sulcata* Born (×6)
2. *Distorsio clathrata* Lamarck (×3)
3. *Murex cabriti* Bernardi (×4)
4. *Murex pazi* Crosse (×4)
5. *Muricopsis oxytatus* M. Smith (×4)
6. *Antillophos* sp. (×4)
7. *Antillophos candei* Orbigny (×3)
8. *Engoniophos* sp. (×4)
9. *Nassarius* cf. *albus* Say (×4)
10. *Nassarius* sp. (×4)
11. *Olivella* sp. "A" (×6)
12. *Olivella* sp. "B" (×4)
13. *Olivella* sp. "C" (×4)
14. *Olivella* sp. "D" (×4)
15. *Olivella* cf. *nivea* Gmelin (×6)

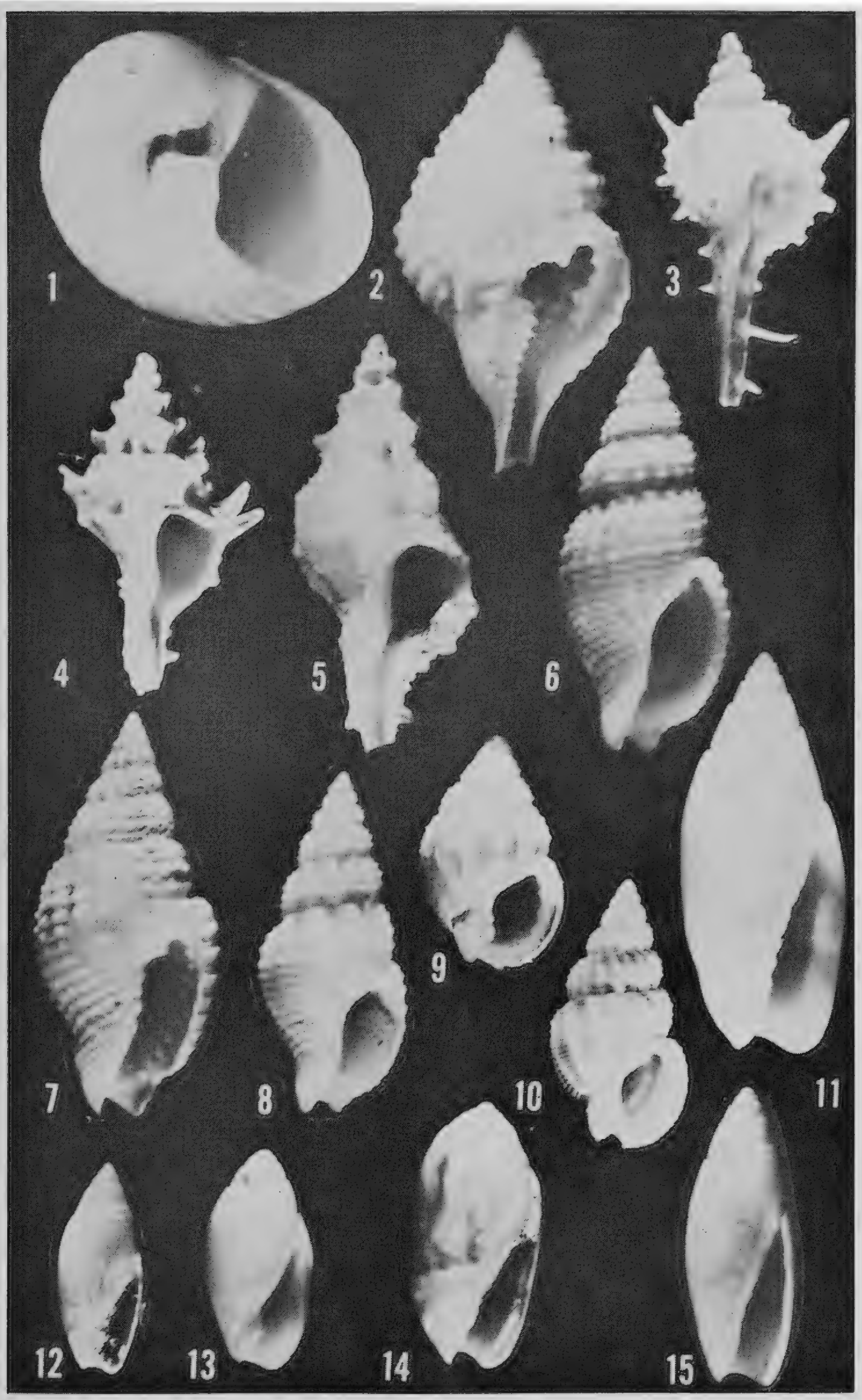
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PLATE 6

1. *Mitra nodulosa* Gmelin (×10)
2. *Mitra styria* Dall (×4)
3. *Cancellaria smithii* Dall (×4)
4. *Marginella aureocincta* Stearns (×15)
5. *Prunum* sp. (×3)
6. *Prunum virginianum* Conrad (×6)
7. *Prunum* cf. *amabile* Redfield (×4)
8. *Prunum labiatum* Kiener (same size)
9. *Conus austini* Rehder and Abbott (×3)
10. *Terebra protexta* Conrad (×4)
11. *Terebra concava* Say (×4)
12. *Terebra* cf. *limatula* Dall (×6)
13. *Terebra* sp. (×3)
14. *Terebra floridana* Dall (juvenile) (×3)
15. *Pyrgocythara coxi* Fargo (×15)
16. *Pyrgocythara* sp. (×15)

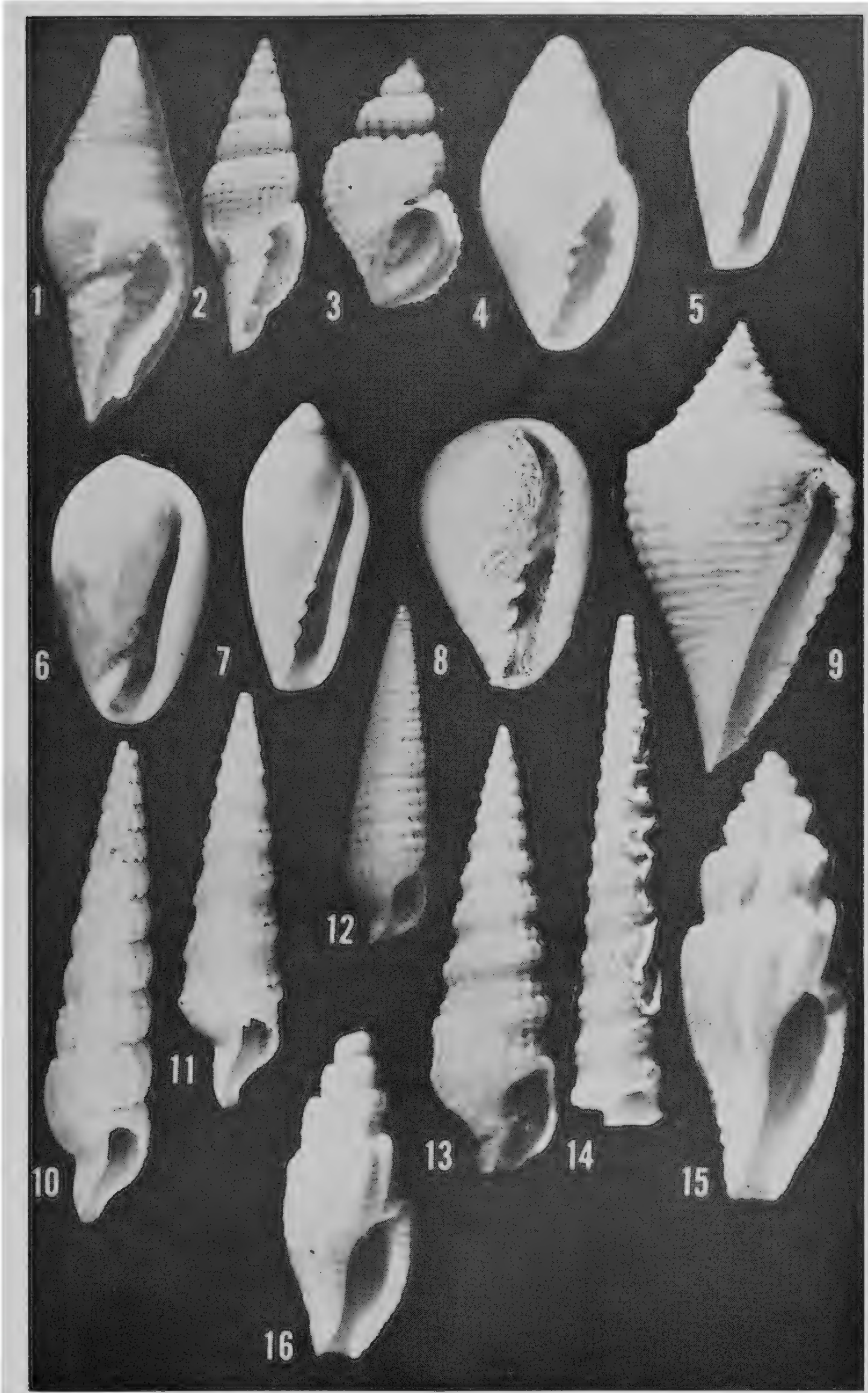
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PLATE 7

1. *Leptadrilla splendida* Bartsch (×3)
2. *Ancistrosyrinx radiata* Dall (×4)
3. *Polystira florencae* Bartsch (×3)
4. *Crassispira fuscescens* Reeve (×3)
5. *Drillia acestra* Dall (×3)
6. *Daphnella stegeri* McGinty (×6)
7. *Daphnella lymneiformis* Kiener (×4)
8. *Daphnella* sp. (×3)
9. *Mangelia bartletti* Dall (×15)
10. *Vitricythara metria* Dall (×15)
11. *Ithycythara* sp. (×15)
12. *Glyphoturris quadrata rugirima* Dall (×6)
13. *Cythara cymella* Dall (×6)

Unidentified species:

14. "A" (×4)
15. "B" (×4)
16. "C" (×4)
17. "D" (×4)
18. "E" (×4)
19. "F" (×4)

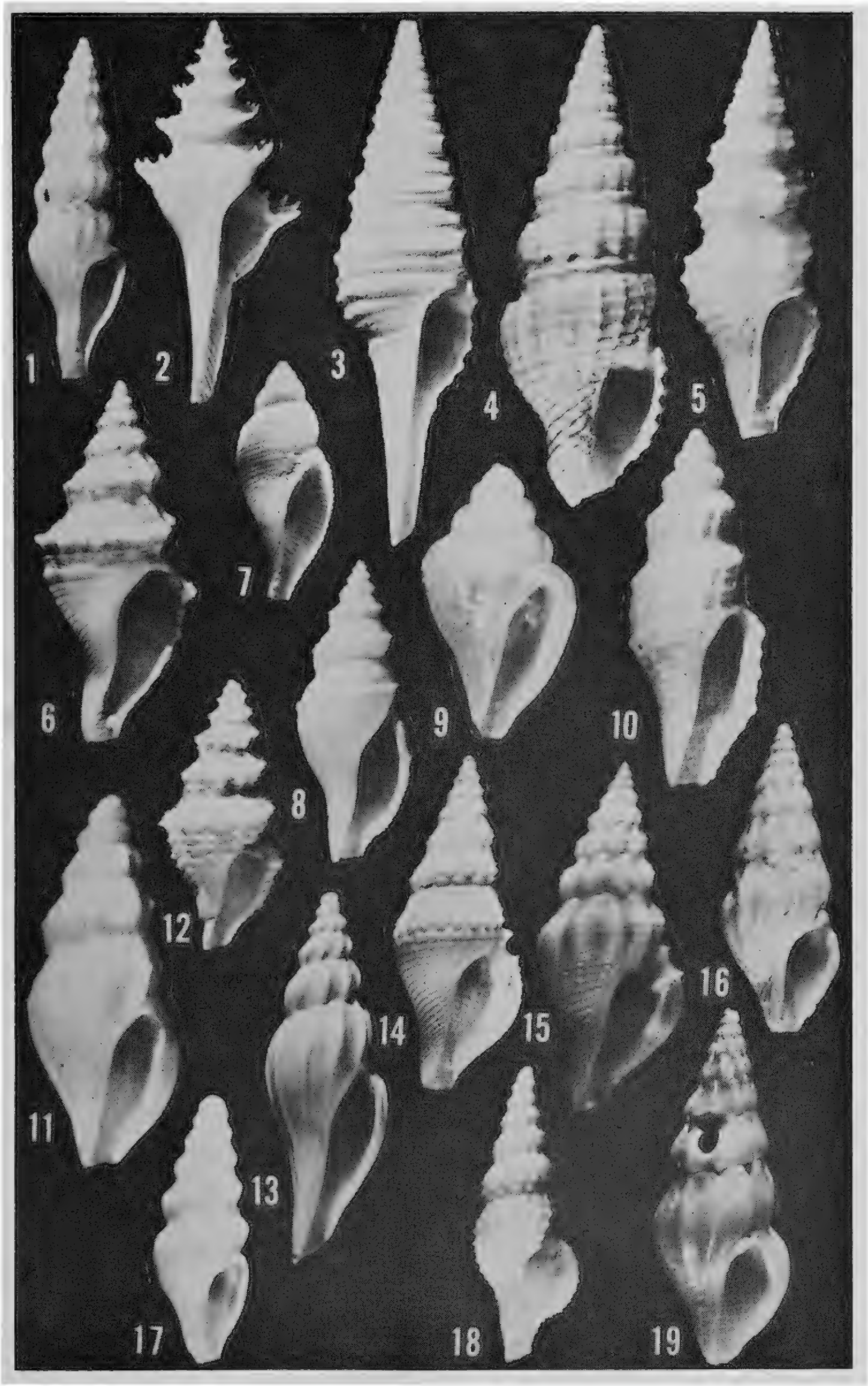
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Plate 8

Unidentified species:

1. "G" (×4)
2. "H" (×4)
3. "I" (×3)
4. "J" (×4)
5. "K" (×4)
6. "L" (×4)
7. *Acteon punctostriatus* C. B. Adams (×15)
8. *Ringicula semistriata* Orbigny (×15)
9. *Atys riiseana* Mörch (×10)
10. *Retusa candei* Orbigny (×10)
11. *Pyrunculus caelatus* Bush (×15)
12. *Rhizorus acutus* Orbigny (×15)
13. *Cylichna* sp. (?) (×15)
14. *Scaphander watsoni* Dall (×4)
15. *Peristichia toreta* Dall (×6)
16. *Cavolina quadridentata* Lesueur (×15)
17. *Cavolina uncinata* Rang (×6)
18. *Cavolina longirostris* Lesueur (×10)

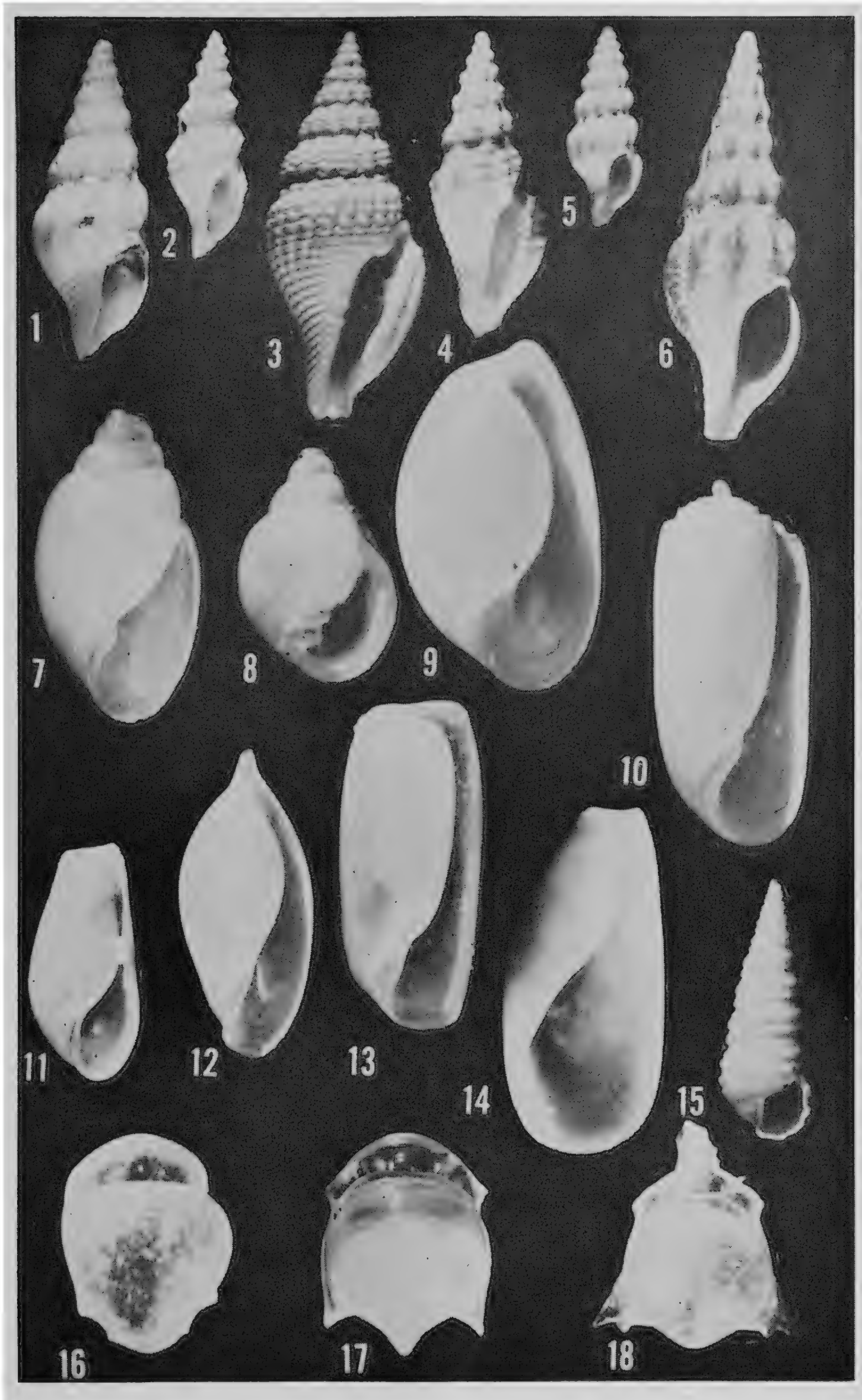
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PLATE 9

1. *Cavolina* species (×4)
2. *Styliola subula* Quoy and Gaimard (×6)
3. *Clio pyramidata* Linné (×6)
4. *Williamia krebsi* Mörch (×10)
5. *Cadulus quadridentatus* Dall (×6)
6. *Cadulus* sp. "A" (×6)
7. *Cadulus* sp. "B" (×6)
8. *Cadulus* sp. "C" (×3)
9. *Dentalium laqueatum* Verrill (×2)
10. *Dentalium sowerbyi* Guilding (×4)
11. *Dentalium* sp. "A" (×2)
12. *Dentalium* sp. "B" (×4)
13. *Dentalium* sp. "C" (×3)
14. *Dentalium* sp. "D" (×3)
15, 16. *Nucula crenulata* A. Adams (×6)
17, 18. *Nuculana acuta* Conrad (×6)

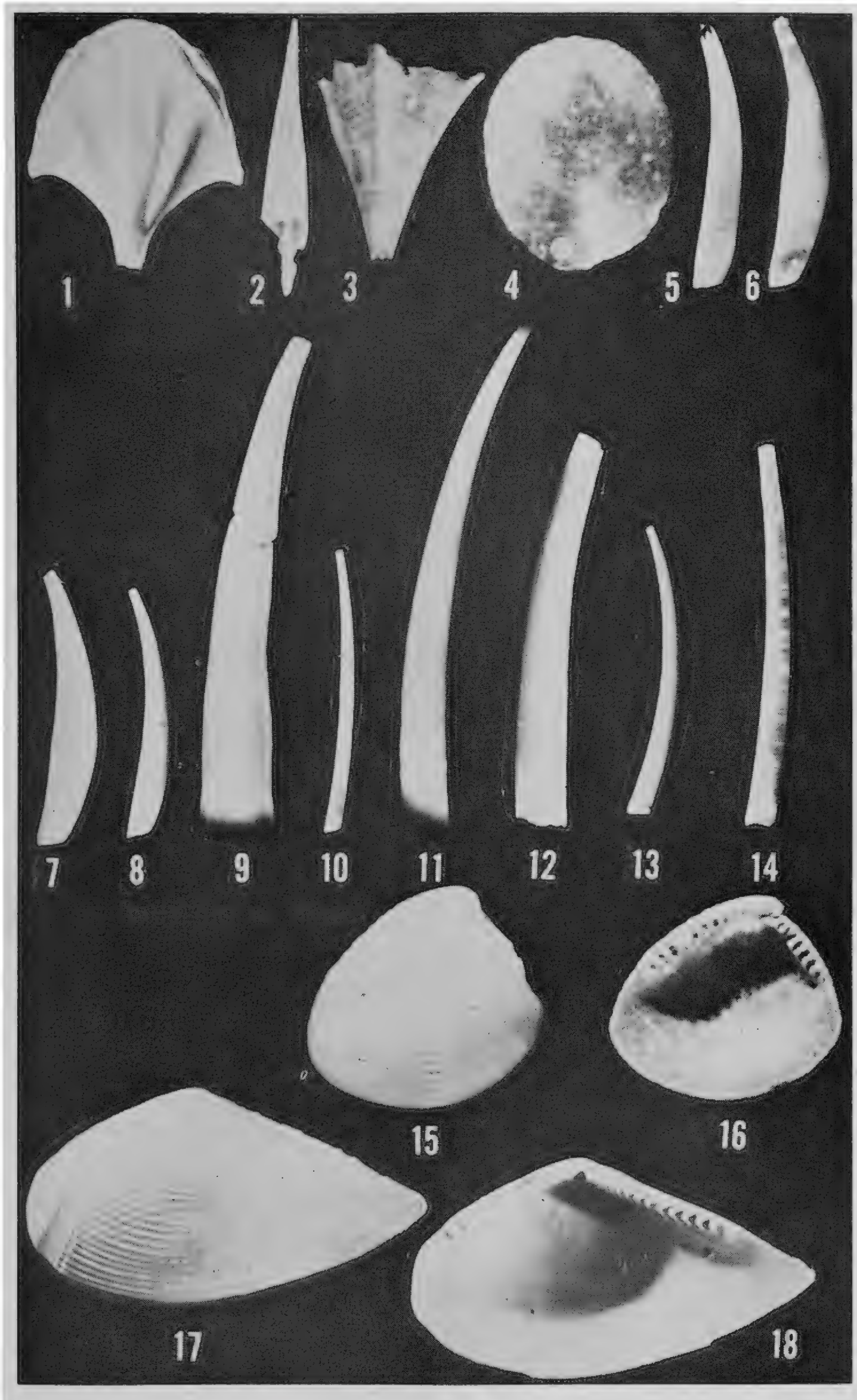
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PLATE 10

1, 2. *Nuculana messanensis* Seguenza (×6)
3, 4. *Nuculana carpenteri* Dall (×4)
5, 6. *Barbatia cancellaria* Lamarck (×4)
7, 8. *Limposis minuta* Philippi (×6)
9, 10. *Limopsis sulcata* Verrill and Bush (×4)

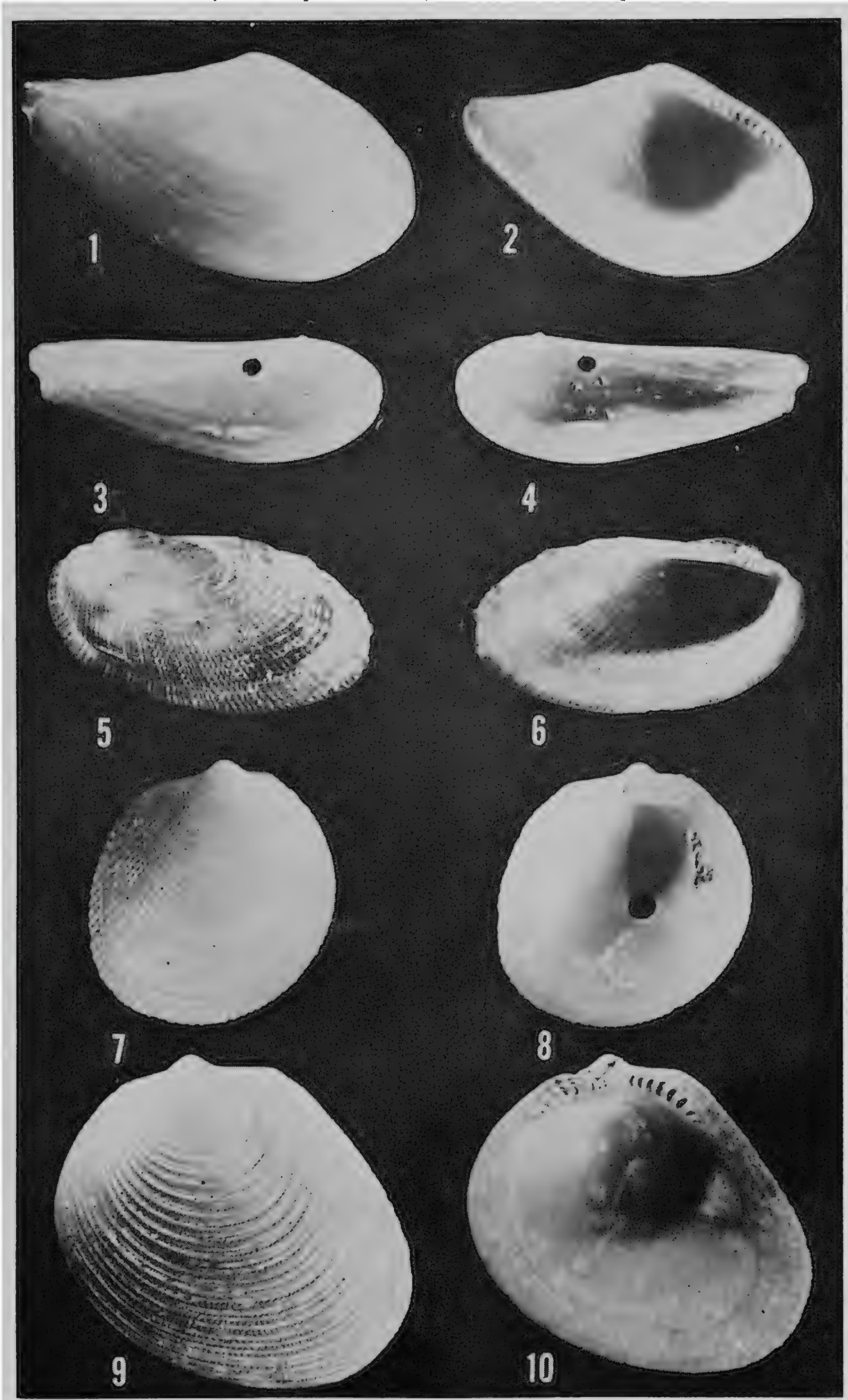
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Plate 11

1, 2. *Plicatula gibbosa* Lamarck (×3)
3, 4. *Chlamys benedicti* Verrill and Bush (×3)
5, 6. *Chlamys nana* Verrill and Bush (×6)
7, 8. *Aequipecten gibbus* Linné (×4)
9, 10. *Aequipecten muscosus* Wood (×4)
11, 12. *Lima pellucida* C. B. Adams (×3)

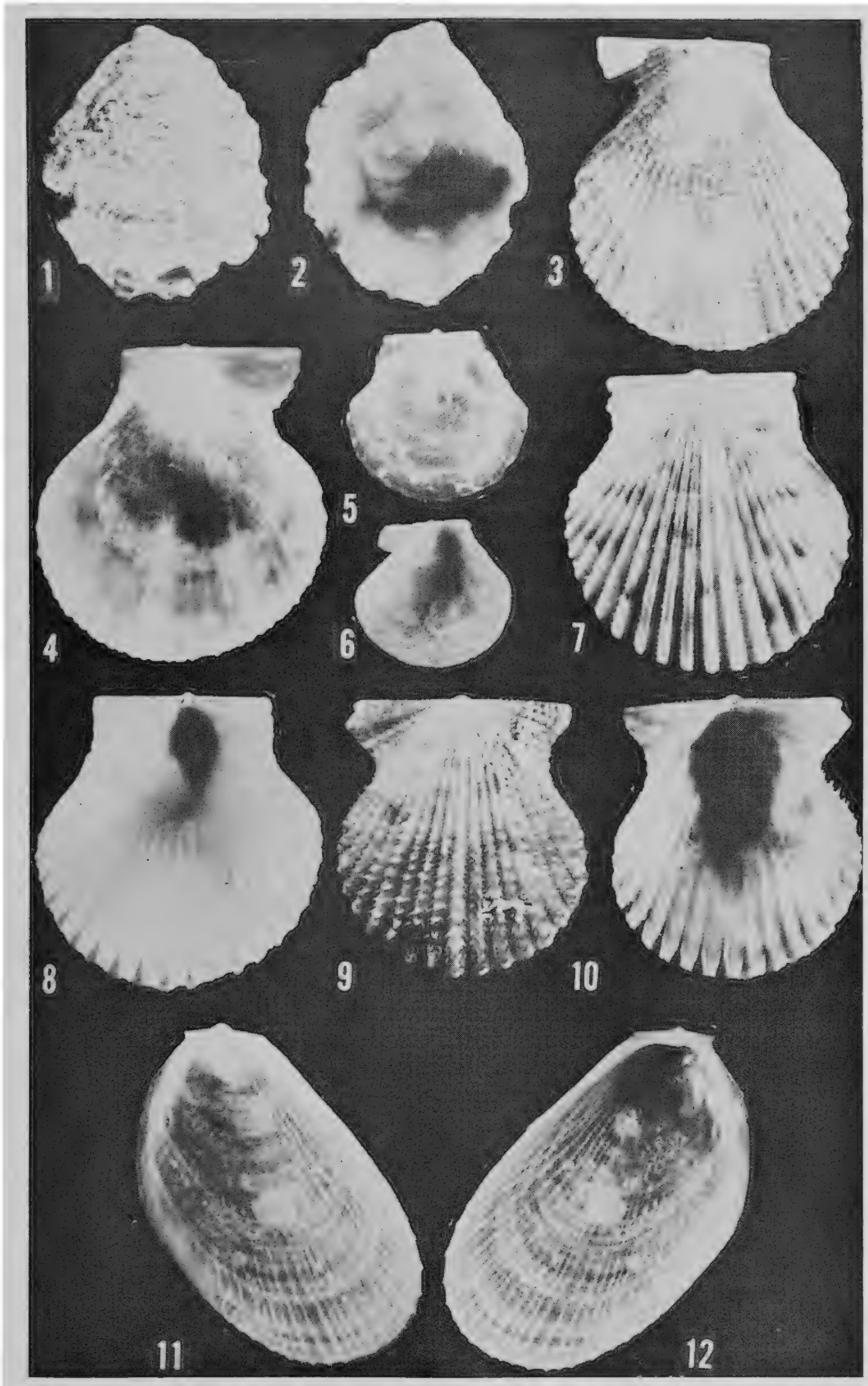
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PLATE 12

1, 2. *Astarte nana* Dall (×6)
3, 4. *Eucrassatella speciosa* A. Adams (×2)
5, 6. *Lucina sombrerensis* Dall (×6)
7, 8. *Phacoides muricatus* Spengler (×4)
9, 10. *Anodontia alba* Link (same size)
11, 12. *Codakia orbiculata* Montagu (×4)

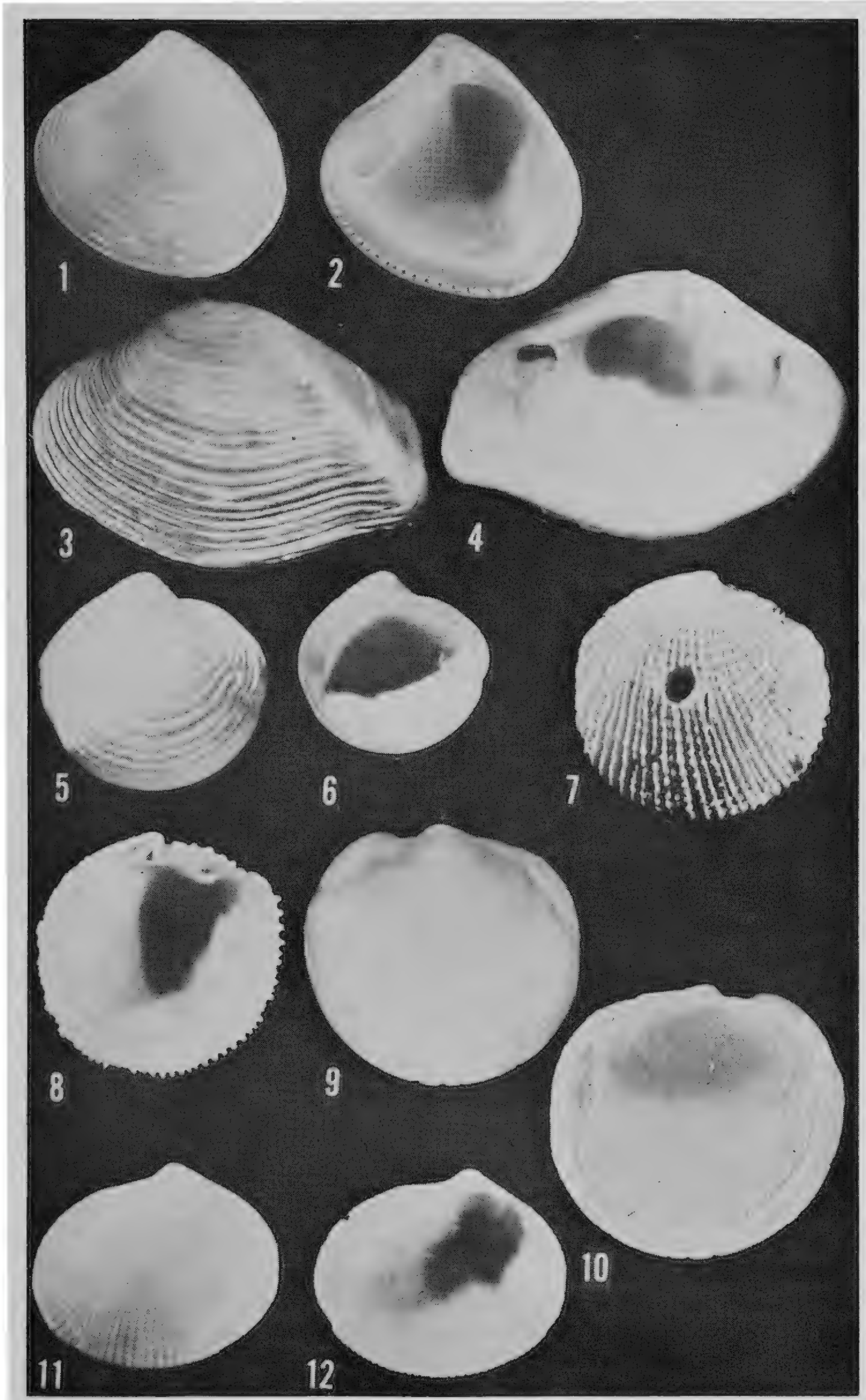
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Plate 13

1, 2. *Laevicardium pictum* Ravenel (×4)
3, 4. *Microcardium tinctum* Dall (×4)
5, 6. *Microcardium peramabile* Dall (×4)
7, 8. *Chione* cf. *paphia* Linné (×3)

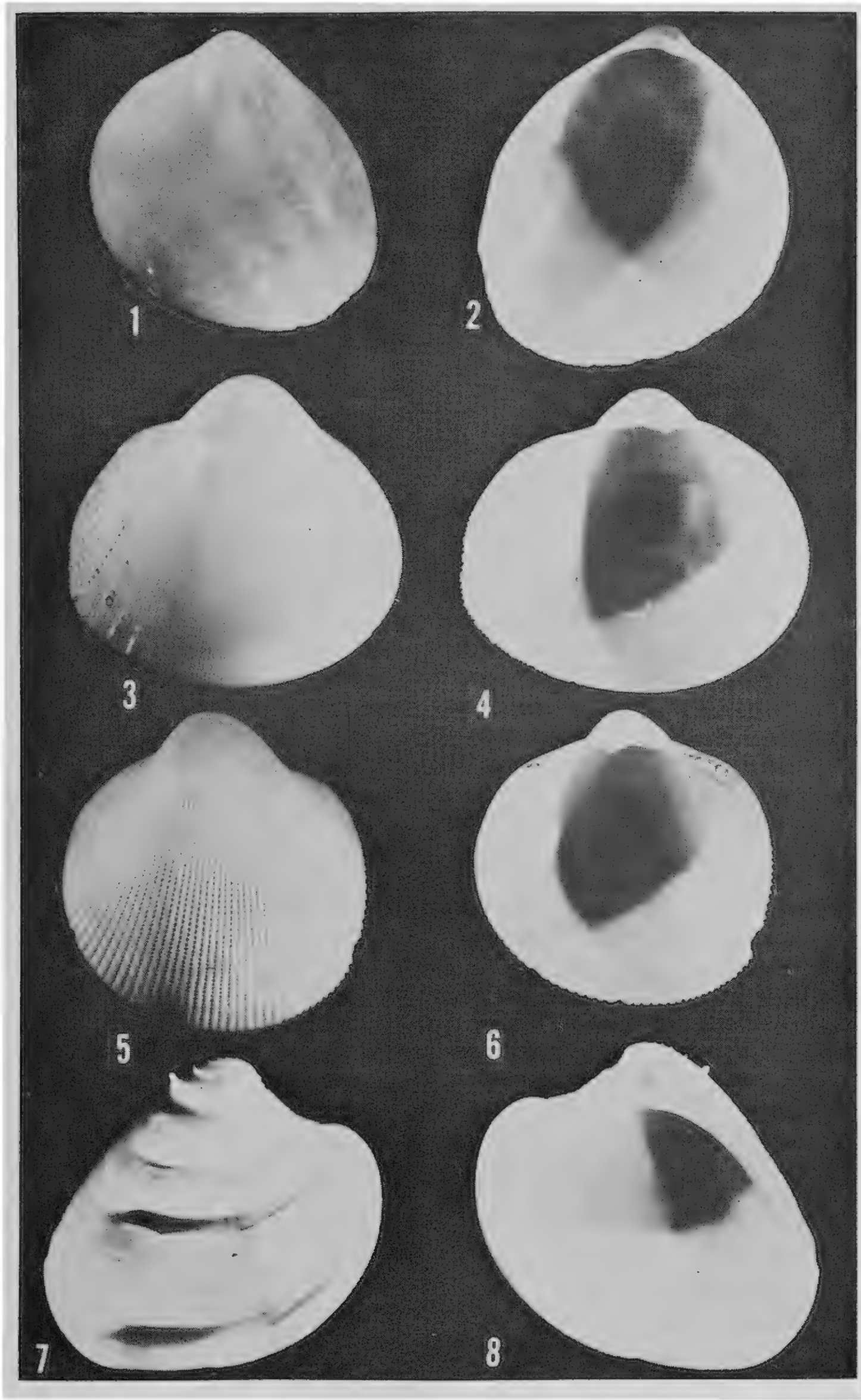
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Plate 14

1, 2. *Americardia guppyi* Thiele (×4)
3, 4. *Gouldia cerina* C. B. Adams (×4)
5, 6. *Gouldia insularis* Dall and Simpson (×6)
7, 8. *Transennella* sp. (×6)
9, 10. *Pitar* cf. *fulminata* Menke (×6)
11, 12. *Pitar* sp. (×3)
13, 14. *Antigona* sp. (×3)

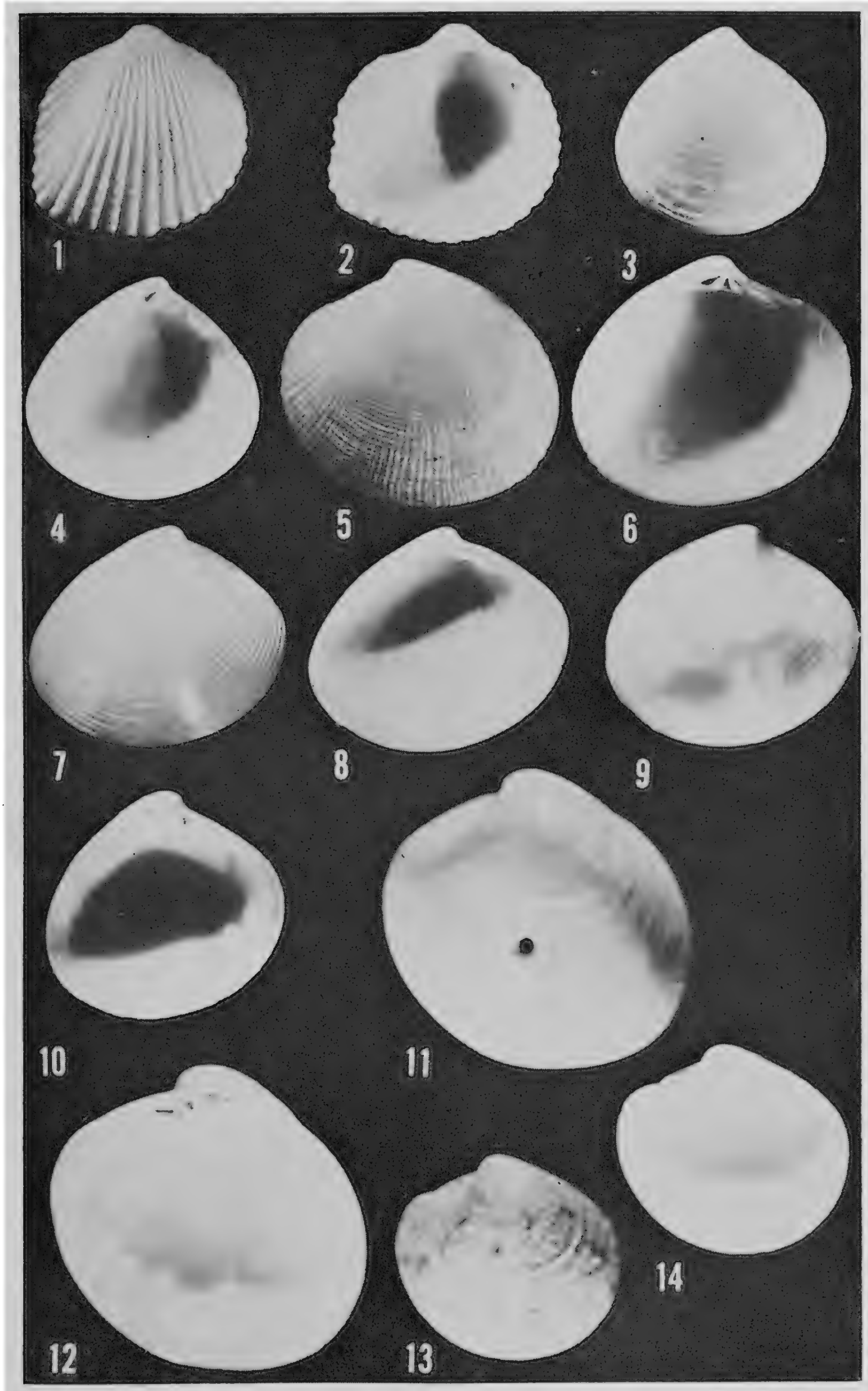
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Plate 15

1, 2. *Tellina* cf. *aequistriata* Say (×4)
3. *Tellina* cf. *versicolor* DeKay (×3)
4, 5. *Phylloda squamifera* Deshayes (×3)
6, 7. *Macoma tenta* Say (×4)
8, 9. *Semele bellastriata* Conrad (×4)
10, 11. *Solecurtus comingianus* Dunker (×3)
12. *Corbula* sp. (×6)

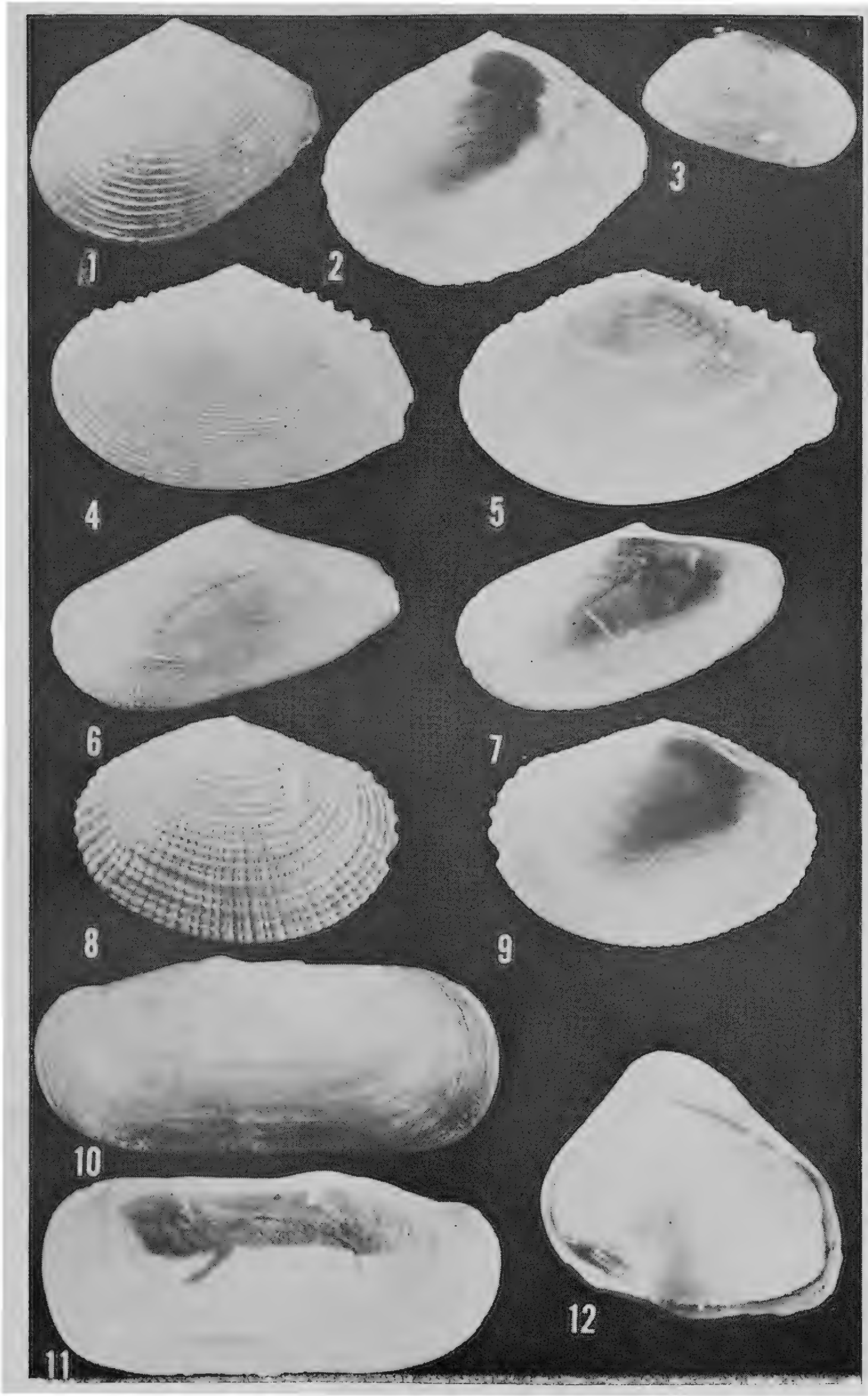
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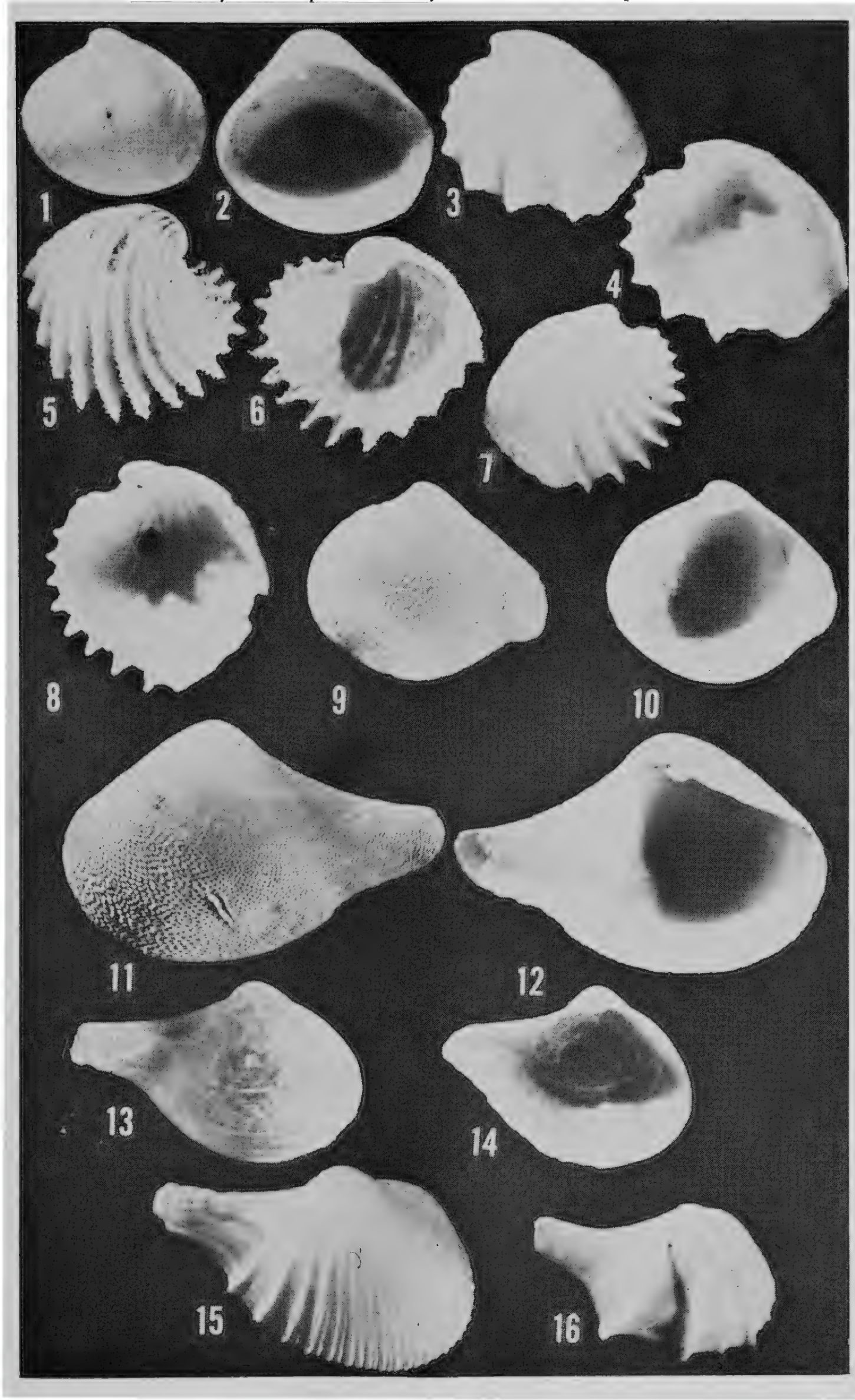
PLATE 16

1, 2. *Notocorbula operculata* Philippi (×10)
3, 4. *Verticordia ornata* Orbigny (×10)
5, 6. *Verticordia fischeriana* Dall (×4)
7, 8. *Verticordia* sp. (×10)
9, 10. *Poromya* cf. *rostrata* Rehder (×4)
11, 12. *Cuspidaria granulata* Dall (×4)
13, 14. *Cuspidaria* cf. *jeffreysi* Dall (×6)
15. *Cardiomya perrostrata* Dall (×6)
16. *Cardiomya ornatissima* Orbigny (×6)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Addendum

At the time a previous paper (Rice and Kornicker, 1962) was printed, identification of some material was incomplete. Listed here are 16 additional species from Alacran Reef, Campeche Bank, Mexico. With the few exceptions indicated, identifications were made by Dr. Robert Robertson. The Academy of Natural Sciences of Philadelphia. These specimens have been placed in the Mollusk Collection, Institute of Marine Science, Port Aransas, Texas.

GASTROPODA

TROCHIDAE

Genus *Synaptocochlea* Pilsbry 1890

Synaptocochlea picta Orbigny

TURBINIDAE

Genus *Arene* H. and A. Adams 1854

Arene riisei Rehder

RISSOIDAE

Genus *Rissoina* Orbigny 1840

Rissoina fenestrata Schwartz

VITRINLELLIDAE

Genus *Parviturboides* Pilsbry and McGinty 1950

Parviturboides comptus Woodring

CERITHIIDAE

Genus *Alabina* Dall 1902

Alabina sp.[1]

TRIPHORIDAE

Genus *Triphora* Blainville 1828

Triphora turris-thomae Holten

EPITONIIDAE

Genus *Epitonium* Röding 1798

Epitonium echinaticostum Orbigny[1]

MURICIDAE

Genus *Aspella* Mörch 1877

Aspella paupercula C. B. Adams[1]

COLUMBELLIDAE

Genus *Mitrella* Risso 1826

Mitrella fenestrata C. B. Adams[1]

MITRIDAE

Genus *Mitra* Lamarck 1799

Mitra florilana Dall

Genus *Pusia* Swainson 1840

Pusia hanleyi Dohrn[1]

TURRIDAE

Genus *Mangelia* Risso 1826

Mangelia bartletti Dall

Genus *Glyphoturris* Woodring 1928

Glyphoturris quadrata rugirima Dall

PYRAMIDELLIDAE

Genus *Triptychus* Mörch 1875

Triptychus niveus Mörch

PELECYPODA

VENERIDAE

Genus *Chione* Mühlfeld 1811

Chione pygmaea Lamarck

Genus *Transennella* Dall 1883

Transennella sp.[1]

[1] Det. Rice.

Fixing of Fallout Material by Floating Marine Organisms, *Sargassum fluitans* and *S. natans*

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Abstract

Gamma spectrometry studies of *Sargassum fluitans* and *S. natans*, a free floating marine algae common to the Caribbean area, indicate concentration of several radionuclides. Owing to the time interval since the last atmospheric tests, only those isotopes whose half-life exceeds 30 days were considered in peak identification. Of these Zr^{95}, Ce^{144}-Pr^{144}, Cs^{137}, Ru^{103}-Rh^{103}, Ru^{106}-Rh^{106} and Mn^{54} were detected. Other radionuclides are strongly indicated—but not positively identified. Inasmuch as the Z number of none of the isotopes identified exceeds 82, it is clear that the activity present cannot be attributed to the natural radioactivity known to exist in a normal marine environment.

The samples were ignited at 400–500 C for four hours, cooled and then compressed into ⅛ in. by 2 in. diameter aluminum planchets for counting by a 256 channel analyser with a 3 inch by 3 inch diameter NaI(Tl) crystal. Spectra for 0 to 2.5 Mev. were scanned in five energy intervals; namely 0 to 0.2 Mev., 0.2 to 0.4 Mev., 0.4 to 0.6 Mev., 0.6 to 1.4 Mev. and 1.4 to 2.5 Mev. Net counts per unit time per energy interval were compiled to give the full spectrum of 0 to 2.5 Mev. for each sample.

Introduction

The recent introduction of fission, and neutron induced products into the marine environment primarily by fallout but also by disposal into fresh water streams which subsequently empty into the sea has precipitated considerable controversy concerning both the mechanisms of dispersion and incorporation of these products into the different organisms found in the oceans. Several investigators have amply demonstrated the ability of various marine organisms to concentrate radionuclide products.

It is not our intention in this report to review this literature in detail. Noteworthy, however, has been the work of Osterberg and co-workers (1962, 1963a and 1963b) who demonstrated the uptake of Zn^{65} by Euphausids and of Zr^{95}-Nb^{95} and $Ce^{141-144}$ by sea cucumbers and other forms. Similarly, Burkholder (1963) reported on the uptake of these nuclides by various kinds of phytoplankton and marine algae. For obvious reasons, studies in this field are expanding (as is the literature on the subject) : however, considerable work remains to be done before we can confidently predict the ultimate disposition of the several long-lived nuclides now present in the marine environment, let alone speculate what might happen to future additions.

Experimental

Samples of two species, *S. fluitans* and *S. natans*, were collected in October 1963 from the Gulf of Mexico in the eastern portion of the Sigsbee Deep (approximately 92° W, 24° N). Immediately after collection, the specimens were stored in one gallon polyethylene jars to which 50 ml of $CHCl_3$ was added as a preservative. Wet weights were not determined.

[1] Department of Oceanography and Meteorology.
[2] Radiological Safety Office.

Upon return to the laboratory, the samples (specimens) were shaken out and cleaned of as much of the parasite life as possible, air dried at 100 C and subsequently ashed at 400–500 C for four hours in a muffle furnace. Loss on ignition average 80% by weight. The ashed sample was then ground in a ceramic mortar and pestle until the material passed a 100 mesh sieve (150 microns). Finally the powders were pressed into ⅛ in. by 2 in. diameter aluminum planchets for counting. Mean weight per counting sample was 3.7 grams.

Two modes of counting were utilized. First, spectra were accumulated on a 256 channel (Radiation Counter Laboratories) analyser using a 3 in. by 3 in. diameter NaI(Tl) detector. Five and ten hour counting times were employed. In order to obtain maximal resolution, the energy scale was expanded such that spectra were obtained for five energy bands encompassing approximately 0 to 0.2 Mev., 0.2 to 0.4 Mev., 0.4 to 0.6 Mev., 0.6 to 1.4 Mev., and 1.4 to 2.5 Mev. These spectra were corrected for background. In the second counting mode, beta-gamma coincidence was used to obtain greater sensitivity. Here, a thin window, gas flow proportional detector was mounted on top of the sample which was mounted on the scintillation detector and used to gate the multichannel analyser. A single channel analyser in the gating circuit of the multichannel analyser allowed broad bands of beta energies to be selected to satisfy the coincidence criteria. This arrangement permitted discrimination in favor of certain fission products. However, owing to such discrimination and the thickness of the sample, this method was inappropriate for total activity determination. Spectra of the energy bands similar to those found in the ordinary gamma spectroanalysis were obtained using 20 hour counting times.

Gross beta and gamma activities of the samples were measured with a 7 in. two pi windowless, gas flow proportional detector using P-10 counting gas and operated as a Geiger-Mueller detector using Q-gas. The sample powder was spread uniformly in a 6 in. stainless steel planchet, purged in the detector and counted. An experimentally determined self absorption factor (using ground carbon to simulate the sample) of 0.9 was used in estimating beta activities.

The criteria for spectral analysis was that a significant gamma energy peak correspond to a fission product with a half-life greater than 30 days or to a radioisotope established in the literature as being present in sea water (Picciotto, 1962). Miyake (1963) and others have identified Co^{60}, Zn^{65}, Mn^{54}, and Fe^{55} as the principal nonfission products in ocean waters.

Results and Discussion

Fig. 1 shows a composite γ spectrum obtained from *Sargassum*. The fission product chain Ce^{144}-Pr^{144} was identified from the three low energy peaks of Ce^{144} (0.041, 0.080, and 1.134 Mev.) and the 1.4 and 2.18 Mev. Pr^{144} peaks. The Ru^{106}-Rh^{106} chain was identified by the 0.51 Mev. and 0.62 Mev. peaks of Rh^{106}; Cs^{137} by the 0.662 Mev. Ba^{137m} internal transition peak; and the Zr^{95}-Nb^{95} chain by the broad peak between 0.7 and 0.8 Mev.; Mn^{54} is indicated by the 0.84 Mev. peak. Appropriate standards were used for calibration purposes.

The Ru^{103}-Rh^{103m} chain is indicated as present owing to the fact that by beta-gamma coincidence counting the Rh^{106} peaks could be virtually eliminated leaving the 0.49 Mev.

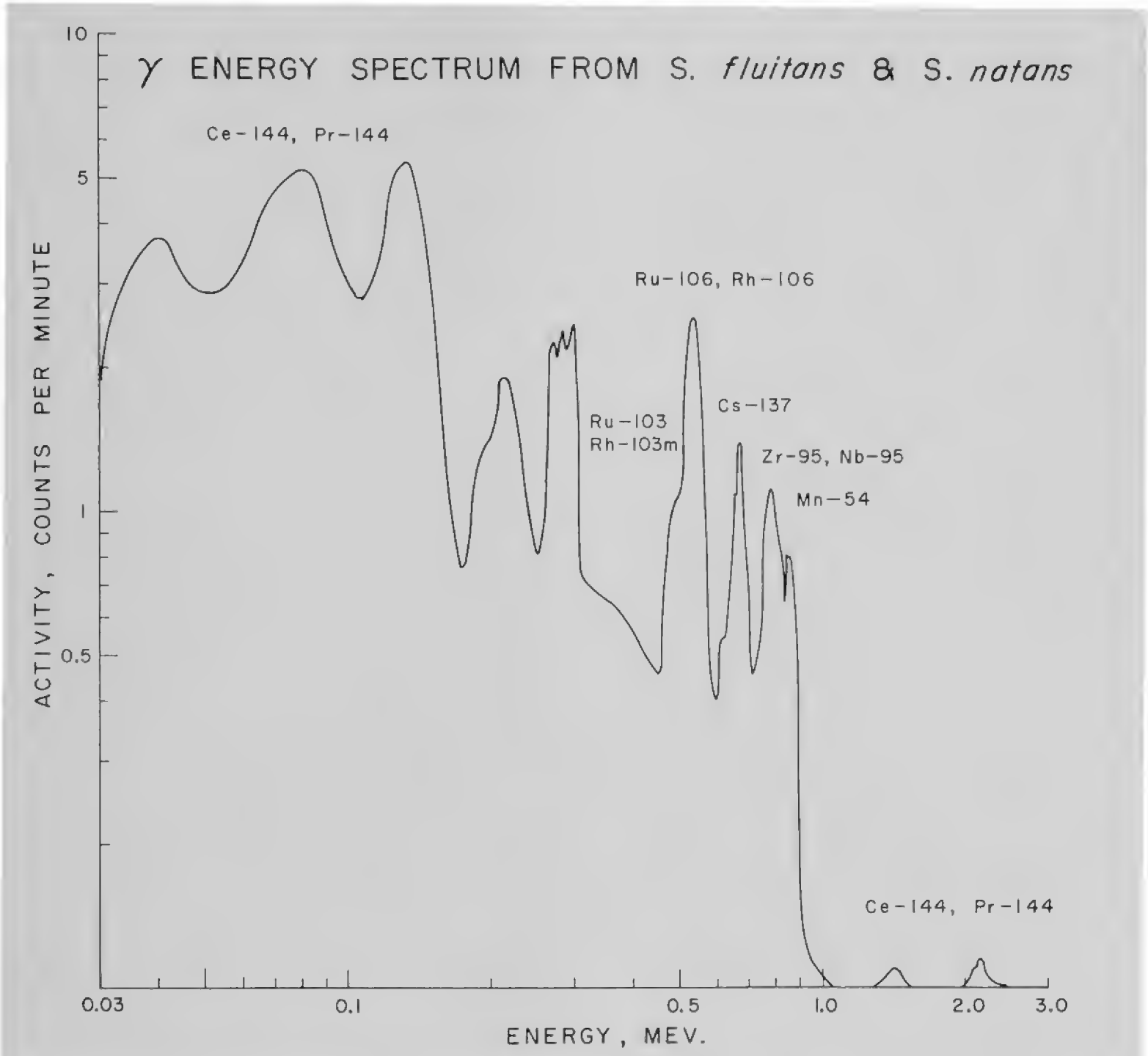

Figure 1

peak (Ru^{103}) and a small 0.61 Mev. (Ru^{103}) peak. It should be noted, however, that this procedure may have exaggerated the importance of the activity present. The peak at 0.215 Mev. did not fit any of the analytical criteria adopted. It is suggested, however, that this peak may be due to isotopes in the natural decay chains (U^{238}, U^{235}, and Th^{232}). The presence of these isotopes would also explain the excessive height of the 0.080 Mev. Ce^{144} peak; Weisner (1938) long ago reported large concentrations of radium and progeny in marine algae and it seems logical that similar concentrations would occur in *Sargassum*. That the 0.215 Mev. peak may have been due to the Te^{125}-Sb^{125} pair was considered. However, the other major peaks (0.175, 0.43 and 0.60 Mev.) in this decay are not clearly indicated. Sb^{125} has the requisite half life ($T_{1/2} = 2.7y$) but to our knowledge it has not been observed in organisms; its presence in these samples is possible but is not proven. Recently, Sb^{125} has been identified in surface water of the Gulf of Mexico (J. Frank Slowey, personal communication), so the possibility of concentration by some organism does exist and deserves further investigation. Owing to its low yield, the source of the Sb^{125} is unclear.

A broad band (0.25–0.3 Mev.), difficult to resolve, may be significant but could not be identified as due to any fission product. This is included in Table 1 under the "others" category.

TABLE 1

Fractional concentration of γ emitters detected in *S. fluitans* and *S. natans*

Isotopes	Per cent spectrum	Yield $\mu\mu c/gm$
Ce^{144}-Pr^{144}	32	15.0
Ru^{106}-Rh^{106}	17	7.9
Zr^{95}-Nb^{95}	11	5.1
Cs^{137}	11	5.1
Ru^{103}-Rh^{103m}	5	2.3
Mn^{54}	5	2.3
Others	19	8.7
Pure β	....	6.5
	100	

Table 1 lists the isotopes identified in this investigation with the percentages of the total gamma spectrum and the yields which they represent. The percentages correspond reasonably well with those found by Miyake (1963) and Osterberg (1962) with the exception of the Zr^{95}-Nb^{95} chain which has a lower relative concentration here. Recently, Shelby (1963) reported a gamma spectral analysis of *Sargassum* washed upon the shores of South Texas near Aransas Pass following a hurricane. He reports a greater activity of Zr^{95}-Nb^{95} than we obtained; however, his samples were taken considerably before these reported here and the discrepancy can be accounted for by normal decay.

The yields represent order of magnitude values. The data were calculated from the total assay measured in a flow detector and corrected to the percentage of the gamma spectrum. The beta residue, which in all probability is due to the Sr-Y chain(s) represents the activity in the proportional detector corrected for Ru^{106} activity.

These studies complement those by Glazunov et al. (1963) from an investigation of *Cystoseira barbata*, a benthonic form of algae common to the Black Sea area. For comparison their data are given in Table 2.

TABLE 2

Gamma emitters detected in *Cystoseira barbata* (from Glazunov et al. 1963)

Isotope	Activity (c/g ash)	
Ce^{144}-Pr^{144}	3.00×10^{-10}	
Zr^{95}-Nb^{95}	0.70×10^{-10}	
		content Sept., 1959
Ru^{103}-Rh^{103}	1.30×10^{-10}	
Ru^{106}-Rb^{106}	0.70×10^{-10}	
Ce^{144}-Pr^{144}	0.17×10^{-10}	content Nov., 1960

CHEMISTRY

It is not our intent here to discuss in detail the chemical composition of *Sargassum*; however, as part of the investigation of the fallout nuclides, a brief study was made of the trace element content of *S. fluitans* and *natans*. To our knowledge no detailed investigation of the trace element content of these plants has been reported. In order to

obtain data on a maximum number of elements in a minimum time, the samples were examined by quantitative emission spectrography (National Spectrographic Lab Inc., Cleveland, Ohio) for the following elements: Cr, Ni, Mn, Fe, Al, Ti, Co, V, Cu, Mo, Pb, Zn and W. Of these elements only Al, Ti, Mn, Fe and Cu were present in substantial amounts. The other elements were present but in amounts less than that indicated—Cr, Ni, Mo, Co < 20 ppm, Pb and V < 50 ppm and Zn and W < 200 ppm.

Table 3 presents the measured concentrations of Fe, Mn, Ti, Al and Cu in *S. fluitans* and *natans*.

TABLE 3

Trace elements in *S. fluitans* and *S. natans*

Element	Concentration (ppm) ashed sample	Normalized to Fe	Sea water $\times 10^{-3}$ (ppm)[1]
Al	1000	3.30	2.0
Fe	400	1.00	2.6
Ti	280	1.80	1.0
Mn	220	0.45	3.0
Cu	50	0.41	0.8

[1] Primarily from Hood (1963).

Even allowing for loss of weight on ignition, the data (normalized to Fe) indicates that *Sargassum* when compared to other marine forms is a relatively poor concentrator of Fe, Mn and Cu, but a good one for Al and Ti. Moreover, the high Al and Ti values are suggestive of a terrestrial source in the form of particulate matter. *Sargassum*, of course, has a good physical shape for particle collection. However, the mechanisms whereby these elements are concentrated in the sea weed are presently unknown.

Conclusions

Definite evidence of the presence of fission products concentrated in or on *S. natans* and *S. fluitans* has been found. This study provided no means of ascertaining whether the activity is adsorbed on the surface or is used physiologically by *S. natans* and *S. fluitans* and thereby fixed within. As noted above, these studies both confirm and extend considerably the work of Glazonov et al. (1963). Thirteen elements (Cr, Ni, Mn, Fe, Al, Ti, Co, V, Cu, Mo, Pb, Zn and W) have been detected in *S. natans* and *fluitans*. Of these, only Al, Ti, Fe, Mn and Cu were present in substantial amounts. Present work is being directed toward a comparison of these results with (1) those obtained from *Sargassum* collected from other areas and (2) those being obtained from prebomb *Sargassum*, in order to yield conclusive evidence as to the relative amount of radionuclides present from natural and/or fission product sources.

Acknowledgments

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The Effect of Hypersalinity on Serum and Muscle Ion Concentrations in the Striped Mullet, *Mugil cephalus* L.[1]

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Abstract

Serum osmolalities and serum and muscle ion concentrations were measured in the striped mullet, *Mugil cephalus* dwelling in salinities from freshwater to 200 per cent sea water. Serum osmotic concentration increased linearly, as did serum ions, with an average slope of 8.5 per cent when compared to increases in environmental concentrations. Muscle ions are more stable, but muscle potassium differs in that it decreases with increased environmental salinity or serum concentration. The relatively well developed homeostatic regulation of serum ions and muscle ions is related to the marked euryhalinity of this species, particularly with respect to the hypersaline environments that it readily penetrates and inhabits.

Introduction

Many types of fishes inhabit hypersaline waters (Gunter, 1945; Simpson and Gunter, 1956; Hedgpeth, 1957; Simmons, 1957; Renfro, 1960; Carpelan, 1961; Zenkevich, 1963). The salinity distributions of the species that penetrate the hypersaline Laguna Madre of the southern Texas coast were reported by Simmons (1957). Simmons collected a total of 53 species in the Laguna Madre at salinities above 35 ppt. Twenty of these species, all of which were teleosts, occurred above 45 ppt, but only 10 were prevalent above 60 ppt.

The most abundant and widely distributed teleost in the Laguna Madre is the striped mullet. Its extreme euryhalinity, at least in Texas water, is exceeded only by some cyprinodonts, particularly *Cyprinodon variegatus* (Gunter, 1946; Simpson and Gunter, 1956), but mullet penetrate fresh waters (Gunter, 1945; Renfro, 1960) and occur at least to salinities of 75–80 ppt (Simmons, 1957; Breuer, 1957). The upper salinity limit for the striped mullet is unknown. The limit probably does not exceed 100 ppt by much, however, since salinities of this magnitude have been related with massive fish mortalities in the Laguna Madre (Collier and Hedgpeth, 1950). *Mugil cephalus* has been reported in salinities as high as 113 ppt in the Sivash (Zenkevich, 1963).

Information about osmotic and ionic regulation in fresh-water, marine, and both anadromous and catadromous teleosts is extensive (*see* Black, 1957; Potts and Parry, 1964). Yet, there is a conspicuous paucity of data about ion concentrations of body-fluids and tissues of teleosts that inhabit hypersaline waters. The early study of Loeb and Wasteneys (1915) established that *Fundulus heteroclitus* was capable of living in

[1] This study was supported by a National Institutes of Health Grant, NIH-6373(A). The research was conducted with facilities available at the Institute of Marine Science, University of Texas, Port Aransas, Texas.

artificial media equivalent to 250 per cent sea water. But survival depended as much on the balance between ionic species as it did on the osmolality of the medium. Increases in body-fluid concentrations followed increases in the medium, but the increases were related also to ion balance in the medium. In general, their results are unsatisfactory since they were based on measurements of pressed juices from entire fish.

Concurrent with studies of penaeid shrimps in hypersaline waters (McFarland and Lee, 1963) osmotic and ion concentrations of serum were determined for striped mullet at increasing concentrations of sea water. The results are reported here, along with data on the major ion concentrations of muscle.

Materials and Methods

Striped mullet, *Mugil cephalus* L., were collected during the summers of 1959 and 1960 from the surfzone along Mustang Island, from the Laguna Madre, and from a large pond on Mustang Island located 10 miles south of Port Aransas, Texas. The pond is filled by the surf during spring storms and tides. Large numbers of surf fishes, including the striped mullet, are isolated in this way within the pond. Following such storms the pond is extensive; approximately ¼ mile in diameter and six feet in depth. Providing there is little rain, its size diminshes during summer from evaporation and its salinity increases. In the summer of 1960 such a condition prevailed. From April through August the salinity rose from approximately 30 to 65 ppt. On August 12, 1960 rain from a heavy thunderstorm filled this pond. Over a two to three hour period the salinity decreased to about 12 ppt. Samples of mullet were obtained just before and after this period.

Several attempts to collect mullet from fresh-water ponds were unproductive. Therefore, mullet were collected from sea water and adapted slowly to tap water over a two-week period. The tap water composition was: osmotic concentration, 49 milliosmols (mO); ions in mEq/l, Cl = 2.4, Na = 2.0, K = 0.2, Ca = 1.4, and Mg = zero. After two additional weeks in tap water the mullet were sampled. Throughout this period they were fed finely chopped liver and shrimp.

Blood samples were withdrawn into a syringe from the opercular sinus and by cardiac puncture, discharged under paraffin oil and the tube chilled on ice. Centrifugation at 2400 g was carried out, usually within one hour. Hemolysis was slight, but samples showing a distinct reddish tinge were discarded.

Osmotic concentrations of 0.2 ml serum and sea water samples were measured by cryoscopy. Serum, muscle and environmental chlorides were determined by the method of Schales and Schales (1941). Sodium, potassium, calcium and magnesium were measured by flame photometry. Specific methods and estimates of error are reported elsewhere (McFarland and Lee, 1963). In general, the error for a measurement is less than 5 percent, but the serum and muscle magnesium values are probably overestimated (Munz and McFarland, 1964).

Collier and Hedgpeth (1950) indicated that the relative abundance of ions in hypersaline water from the Laguna Madre was similar to normal sea water, except that sulfate tended to be low. In this study a different situation prevailed. Sodium was less and magnesium more concentrated than in normal sea water when compared to chloride. The differences amount to ca. 5 per cent for Na and ca. 10 per cent for Mg.

Results

Osmotic and Ionic Concentration of Serum

The serum osmolality of the striped mullet increases linearly from fresh water to 200 per cent sea water (Fig. 1). Serum has a mean osmolality of 342 mO in fresh water and its regression on external salinity is + 0.085 (significantly different from zero slope at $P < 0.01$). Thus, serum has a mean value of 427 mO in 100 per cent sea water (ca. 1000 mO) and 512 mO in 200 per cent sea water. Separate blood samples obtained from four silver mullet, *Mugil curema*, during May 1959 have serum osmotic values that lie along the regression line for striped mullet (Fig. 1). The serum values of the four striped mullet obtained from the Laguna Madre at 1500 mO lie below the regression line, but are included in calculation of the regression. When sampled four days later the serum osmolalities of the two striped mullet, that underwent rapid dilution stress from 1938 to 344 mO during a severe thunderstorm, were still equivalent to the high osmolalities typical of the fish in hypersaline water (Fig. 1).

Concentrations of the major ions in serum samples corresponding to the environmental concentrations of these ions are shown in Fig. 2. Although individual variations for serum K are high (possibly reflecting a slight hemolysis in some samples), the four major cations and chloride all increase in concentration as a function of increased en-

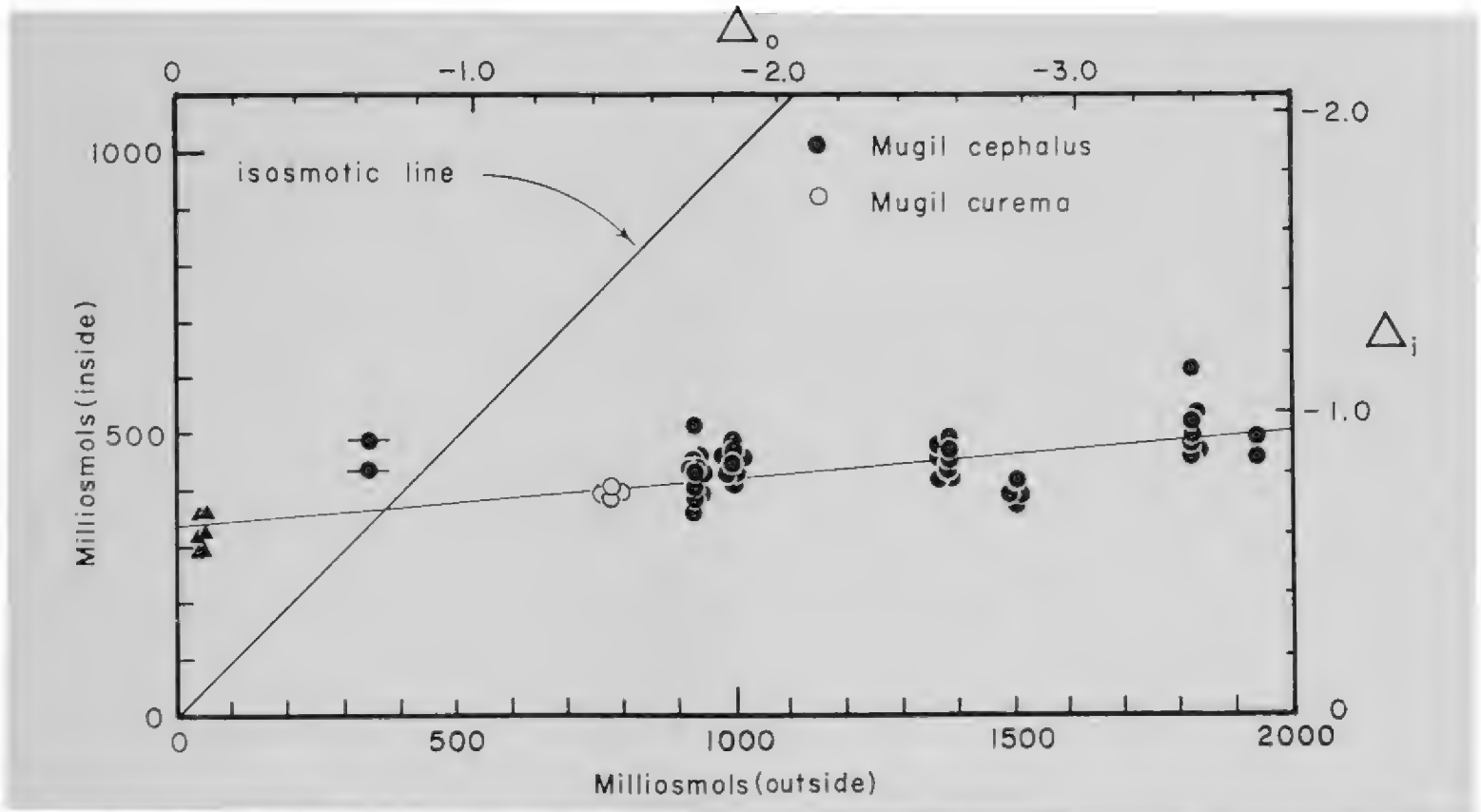

Fig. 1. The effect of environmental osmotic concentration on serum concentration in the striped mullet.

Values are expressed either as milliosmols (mO) or as freezing point depression (Δ). Black circles are serum values for individual mullet collected at the indicated osmotic concentrations. Black triangles are values obtained from six mullet that were collected in sea water (ca. 1000 mO) and adapted for 30 days to fresh water. The two black circles intersected by short horizontal lines represent two specimens sampled at the salinity indicated, but which four days before were inhabiting the highest concentration indicated. The four open circles are specimens of the closely related silver mullet. The equation for the overall regression, $mO_i = 342 + 0.085 mO_o$, was calculated without including the data for the silver mullets or the two striped mullets from 343 mO_o.

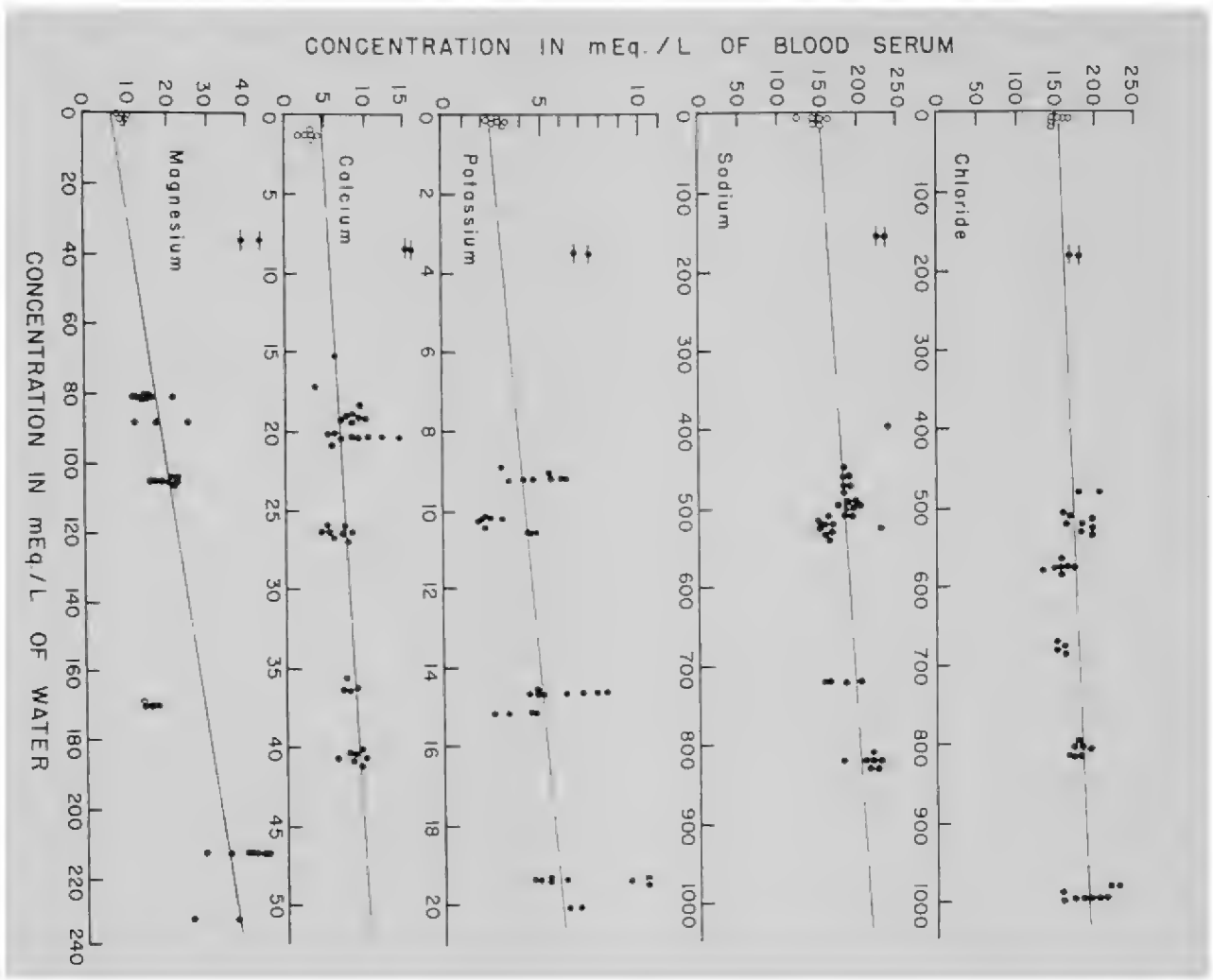

FIG. 2. Relationship between the measured concentrations of serum and environmental ions for the striped mullet.

Black circles are for the fish sampled from the natural environment, whereas the black horizontally barred circles are for the two specimens subjected to natural but severe dilution stress (see Fig. 1 and text). Note that all the serum ions except chloride remained high in these specimens. The overall regression equations for each ion without inclusion of the two former serum samples are: $Cl_i = 153 + 0.036Cl_o$; $Na_i = 151 + 0.063Na_o$; $K_i = 2.35 + 0.181K_o$; $Ca_i = 4.73 + 0.112Ca_o$; and $Mg_i = 6.05 + 0.137Mg_o$. Values are expressed in mEq/l.

vironmental concentration. All the ion regressions have slopes significantly different from zero ($P < 0.01$; Fig. 2). When each serum-ion regression slope is compared to the regression slope of serum-osmotic concentration no significant differences can be established, except for Mg (significant at $P < 0.05$ but not at $P < 0.01$). Since flame photometric procedures for Mg are subject to emission error the validity of this difference is questionable.

The overall mean ratio of the sum of ions, expressed in mM/l, to serum osmotic concentration yields a value of 0.86 ± 0.015 (1SE). If the serum ion values for mullet in 100 per cent sea water are corrected for water content (ca. 92%) a mean ratio of 0.91 ± 0.02 (1SE) is obtained, a value in agreement with similar ratios for other marine teleosts (Robertson, 1954).

Ion Concentrations of Muscle

The water content of muscle decreases as a function of increased serum osmotic concentration. Values for striped mullet are similar to those reported by Gordon (1959a) for brown trout in fresh water and in sea water. Thus, muscle water averages about 85, 80 and 75 per cent respectively, for fish adapted to fresh water, sea water and 200 per cent sea water.

Measurements of muscle ions indicate that Na, Ca, Mg and Cl were relatively constant

throughout the range of salinities studied, but variations at least for Na and Cl, were high. The coefficient of variation for the various samples at given salinities was between 30 and 40 per cent. High values could result from large individual variations but also from slight contamination of samples with Na and Cl. The overall mean values, in mEq/kg muscle water, one standard error of the mean and the sample size for these ions were: Na = 23.7 ± 3.4 (n = 48), Cl = 44.6 ± 2.9 (48), Ca = 5.4 ± 0.4 (49), and Mg = 25.1 ± 1.2 (40).

The concentration of muscle K in contrast to the other muscle ions was not constant but decreased as serum osmotic and ion concentration increased. Mean muscle K concentrations were: fresh-water (49 mO) = 153 ± 4.0 (n = 6), sea water (930–996 mO) = 118 ± 3.8 (23), and ca. 200 per cent sea water (1823 and 1938 mO) = 81 ± 5.1 (9).

Discussion

The only existing work concerning osmotic adjustments in mullet appears to be that of Cummings (1955). Mullet were transferred directly from sea water to various dilutions of sea water including distilled water. Physiological adjustments in three per cent sea water were normally complete within three days and had little effect on mortality. More drastic, acute dilution stresses caused increases in mortality, but gradual dilution resulted in complete adaptation to fresh water. Direct comparisons between Cummings' results and this study can be made only with respect to serum chloride values. He reported approximately 125 mEq Cl/l in salt water adapted mullet. This concentration declined to 100 mEq/l following adaptation to fresh-water. Corresponding values from this study are 173 and 153 mEq Cl/l of serum (Table 1). My values are higher and represent a slightly lesser decrease with dilution: 12 per cent as contrasted to 20 per cent (Table 1).

TABLE 1

Comparison of the serum osmotic and chloride concentrations of several teleosts when in fresh water (FW) and when in sea water (SW). For a more extensive compilation of data see Table 1 *in* Black (1957)

Serum concentrations							
Osmotic conc. (mO)			mM Cl/l				
SW	FW per cent	Per cent decrease	SW	FW	Per cent decrease	Species	Source
427	342	20	173	153	12	*Mugil cephalus*	This study
.....	.....	....	125	100	20	*Mugil cephalus*	Cummings(1955)
380	362	5	.....	.....	....	*Fundulus kansae*	Stanley and Fleming (1964)
350	323	8	.....	. ....	....	*Gasterosteus aculeatus*	Koch & Heuts (1943)
430	323	25	ca.190	ca.145	23.5	*Salvelinus alpinus*	Gordon (1957)
ca.382	323	15.5	ca.160	ca.130	19	*Salmo trutta* 10 day accl.	Gordon (1959a)
342	328	4.5	150	133	11.5	*Salmo trutta* 64 day accl.	Gordon (1959b)
480	270	43.5	150	120?	20	*Salmo gairdneri*	Gordon (1963)
364	320	12	166	130	22	*Salmo salar* smolt	Parry (1961)
400	328	18	158	172(spawn)	108	*Salmo salar* adult	Parry (1961)
447	.....	....	188	.....	....	*Muraena*	Robertson(1954)
.....	294	....	.....	117	....	*Coregonus*	Robertson(1954)
420	339	19	.....	.....	....	*Anguilla anguilla*	Bertin (1956)

A comparison between serum osmotic and chloride concentrations in several euryhaline and a few stenohaline teleosts are presented in Table 1. Although not exhaustive the comparison indicates that euryhaline fishes generally experience, with environmental dilution, similar relative reductions in their serum. In stenohaline teleosts, serum freezing point values typically are considered to range between —0.45 and —0.65 C for fresh-water forms, whereas marine teleosts usually range between —0.65 and —1.1 C (Lockwood, 1964; Potts and Parry, 1964; Prosser and Brown, 1961). Assuming an average of —0.55 as respresentative of fresh-water teleosts and —0.80 as representative of marine teleosts then a difference of near 20 per cent seems general. This agrees with the average reductions found for euryhaline teleosts exposed to sea water and fresh water (Table 1). The critique that uncontrolled variables such as size, sex, season, temperature, etc., may effect and obscure differences within and between the various studies is entirely appropriate. Indeed, the comparisons are less than satisfactory. Nevertheless, the tendency for osmotic and ionic regulation in euryhaline teleosts to show well developed homeostatic ion regulation, although less than perfect, is clear. Prolonged exposure, in fact, in some species can apparently improve the extent of homeostatic regulation (see *Fundulus*, *Gasterosteus* and *Salmo trutta*, Table 1).

More satisfactory comparisons would result if different species were sampled from the same habitat and the serum analyses performed at the same time. On one occasion during this study this was done. The black drum, *Pogonias cromis* and the striped mullet were collected from an hypersaline part of the Laguna Madre and their serum concentrations compared (Table 2). The black drum has significantly higher serum values except for K. This is of particular interest since both species are distributed extensively in brackish water, are taken in fresh water and are among the most abundant fishes in the Laguna Madre up to salinities of at least 75 ppt (Simmons, 1957).

With respect to physiological responses to high salinities the results indicate that euryhaline fishes, as exemplified by the striped mullet, regulate serum ions and osmolality about as well when living in fresh waters as when inhabiting hypersaline waters. Concomitant with the regulation of serum ions is the regulation of muscle ions. Slight increases in ion concentrations may occur between fresh water and sea water adapted mullet, but above this level muscle ions are constant. This regulation is not unexpected, but the inverse relationship between muscle K and increased environmental concentrations (both medium and extracellular fluids) was not anticipated. It is not, however, without precendent. Reduction in muscle K was found under certain conditions for *Salmo salar* in sea water as compared to specimens from fresh water, although salmonids more often show a decrease in, or, no change in muscle K concentrations (Parry, 1961). In euryhaline penaeid shrimp a similar reduction in muscle K occurs and this can be related to hypersaline conditions (McFarland and Lee, 1963). Unlike

TABLE 2

Comparison of serum osmotic and ion concentrations of striped mullet and black drum collected from a salinity of 150 per cent sea water (1505 mO_o) in the Laguna Madre, Texas. Fishes were collected by gill net on August 21, 1959. Values are the means plus and minus two standard errors.

Species	n	mO_i	Na	Cl	K	Ca	Mg
Mugil cephalus	(4)	395±8.1	176±9.2	162±1.7	3.8±0.6	3.7±0.25	7.9±0.4
Pogonias cromis	(7)	468±5.4	197±2.7	183±3.6	4.6±0.9	4.7±0.20	10.2±0.3

mullet, however, muscle K decreases as the shrimp penetrate into fresh water. The highest K concentration occurs when the shrimp are in 100 per cent sea water. Furthermore, another muscle constituent, trimethylamine oxide, decreases in concentration in penaeid shrimp, blue crabs and with less certainty in some teleosts when they are in hypersaline water (McFarland and Parker, unpublished data). The unique decrease in muscle K may involve changes in muscle cell permeabilities or possibly the flux-rates attained by the ion membrane pumps. Whatever the mechanisms the effect may be widespread in organisms that penetrate hypersaline environments.

In summary it can be stated that the striped mullet, at least as found in Texas, offers an excellent opportunity for physiologists to study ion regulation in a fish that inhabits an extensive natural salinity gradient. In this study only the static aspects of ion regulation in striped mullet at high, intermediate and low salinities have been established as highly developed. The dynamic aspects of ion regulation that concern kidney function, extra-renal structures, overall flux rates, permeabilities, etc., remain to be investigated. Furthermore, mullet are often sympatric with other teleosts that for the most part display different lower and upper salinity distributions (Simmons, 1957). As a result a rare opportunity exists to relate the different salinity distributions of these teleosts to possible changes or differences in the physiological mechanisms of ion regulation.

Acknowledgments

I should like to express my appreciation for the technical service rendered by Mr. B. D. Lee. Messrs. E. Simmons and R. Martinez of the Texas Parks and Wildlife Department were most helpful in collecting specimens from the Laguna Madre.

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Calcium Carbonate Deposition Associated With Blue-Green Algal Mats, Baffin Bay, Texas

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Abstract

A distinctive grain type, termed "algal micrite," is forming in association with blue-green algal mats in the Baffin Bay area. This grain type consists essentially of microcrystalline aragonite intermeshed with mucilaginous organic material, and is believed to form by direct precipitation from super-saturated sea water within the lower zones of the mat. The precipitation may be induced by bacterial decomposition of the algal mat.

Introduction

The Baffin Bay complex is situated along the Texas Gulf Coast, some 30 miles south of Corpus Christi, Texas (Fig. 1). High evaporation rates and restricted water circulation result in general hypersalinity within the complex, and this hypersalinity is reflected in the suite of sedimentary grain types being deposited in the area (Rusnak, 1960a). This suite is comprised in part of various non-skeletal, calcium carbonate grain types, including a distinctive grain type which appears to occur almost exclusively in association with the blue-green algal mats of the area. The purpose of this paper is to describe the nature, occurrence, and possible mode of origin of this mat-associated grain type. This work is part of a more complete study of the sediments of Baffin Bay, completed in partial fulfillment of the requirements for an advanced degree at Rice University, Houston, Texas (Dalrymple, 1964). The complete work is intended for publication at a later date.

PETROGRAPHY

In the interests of brevity and convenience, the grain type described herein will be termed, "algal micrite grains," although the unproven genetic implications of this term are recognized. Rusnak (1960a) described similar aggregates from Baffin Bay, but apparently failed to observe the association of aggregates with algal mats. Rusnak (1960a, p. 172) stated that ". . . nearly all the lumps are associated with oolites and carbonate-coated shell fragments . . ."

In reflected light, algal micrite grains are chalky white to cream colored, and display a rough, uneven, exterior surface (Fig. 2A). A wide range of grain sizes has been observed, from one-sixteenth millimeter to more than 200 millimeters in length. The smaller grains are irregularly equant in shape, while the larger grains are invariably flattened and flake-like in appearance. It is apparent that the large, flattened grains are merely cemented aggregates of the smaller, more equant grains, and this interpretation is readily confirmed by thin section examination (Figs. 2B, C).

In thin section, algal micrite grains are seen to consist primarily of randomly dis-

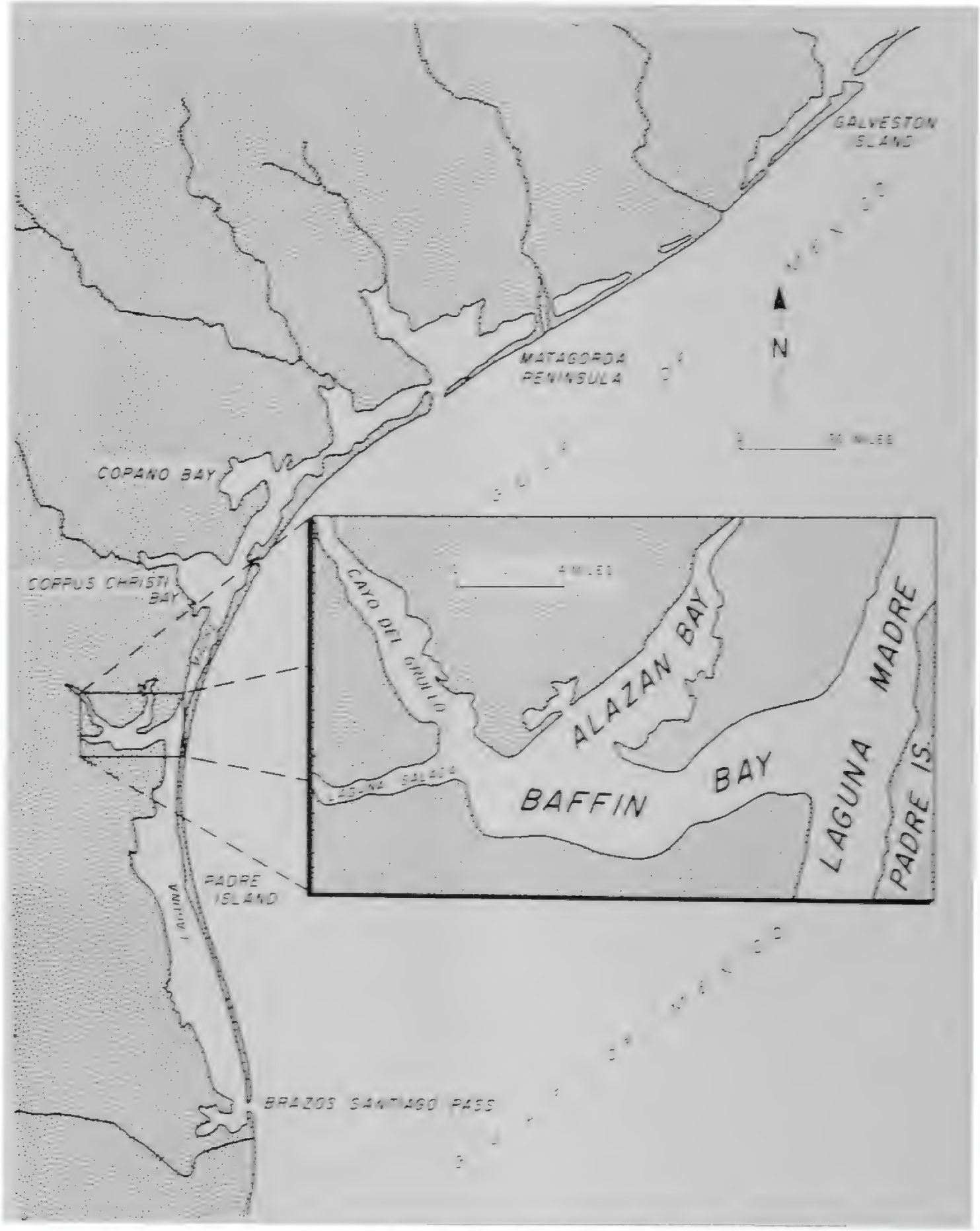
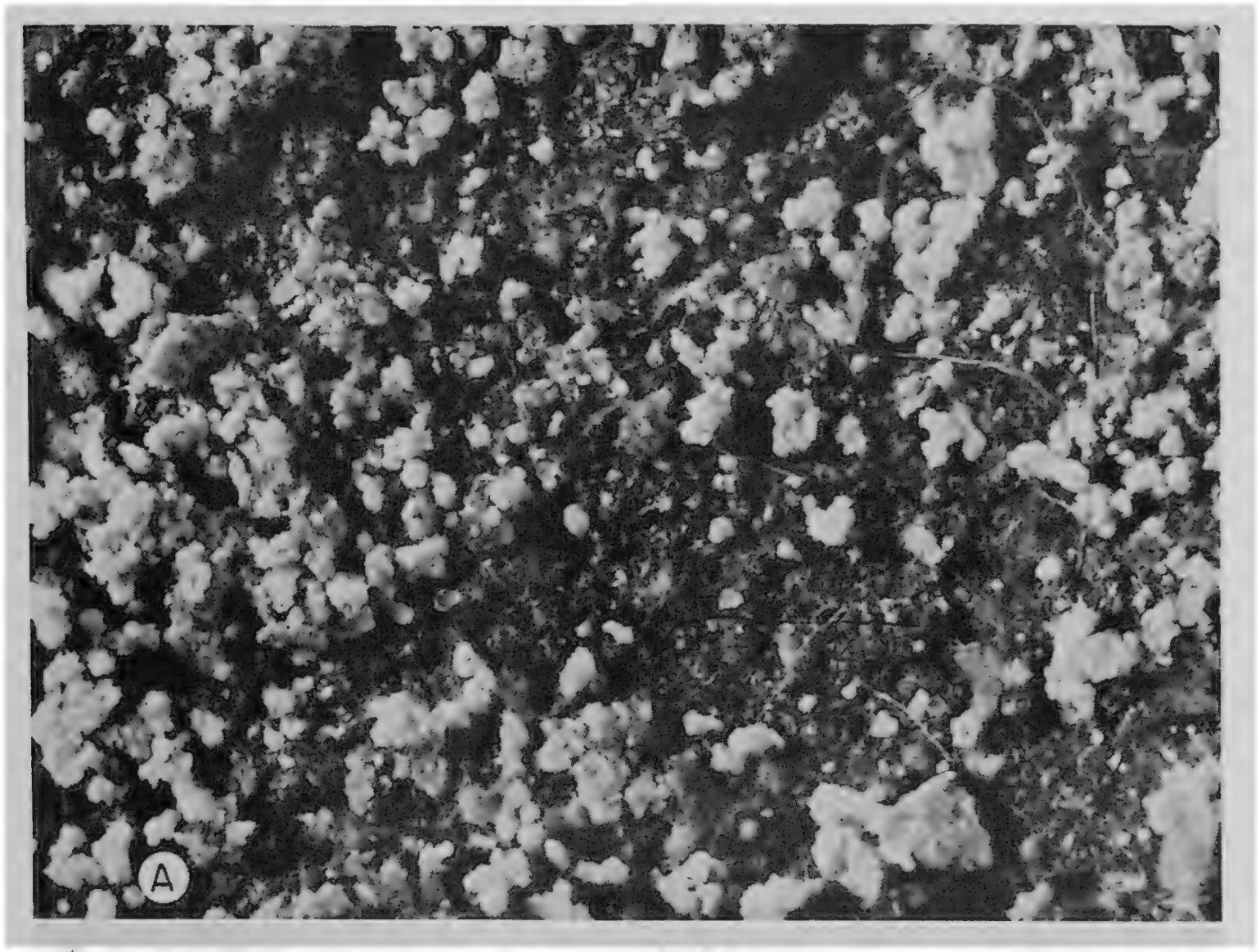


FIG. 1. Index map of Texas Gulf Coast and the Baffin Bay area. After Fisk, 1959.

FIG. 2A. Reflected light photograph of the surface between two layers of an algal-laminated recent stromatolite, Baffin Bay, Texas. The light-colored grains seen on the surface are algal micrite grains. Note the various shapes and states of aggregation of these grains. The dark surface on which the grains are resting is the organic material of the mat itself. Magnification, ×16. B. Thin-section photomicrograph of a small algal micrite grain. This may be a single, "unit" grain, as it is not obviously an aggregate of pre-existing grains (compare with Fig. 2-C). Crossed nicols. ×200. C. Thin-section photomicrograph of a large algal micrite grain, composed of an aggregation of several smaller grains. Note the pore spaces in the interior of the grain (black). Crossed nicols, ×125.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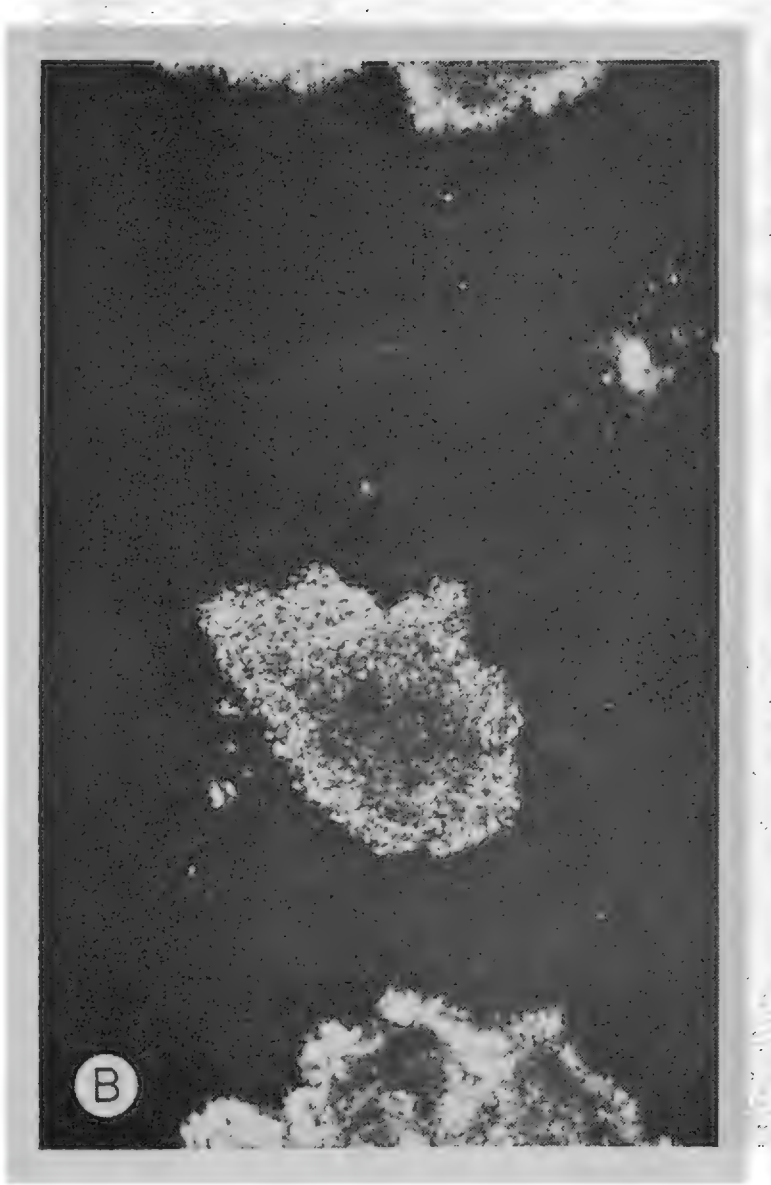
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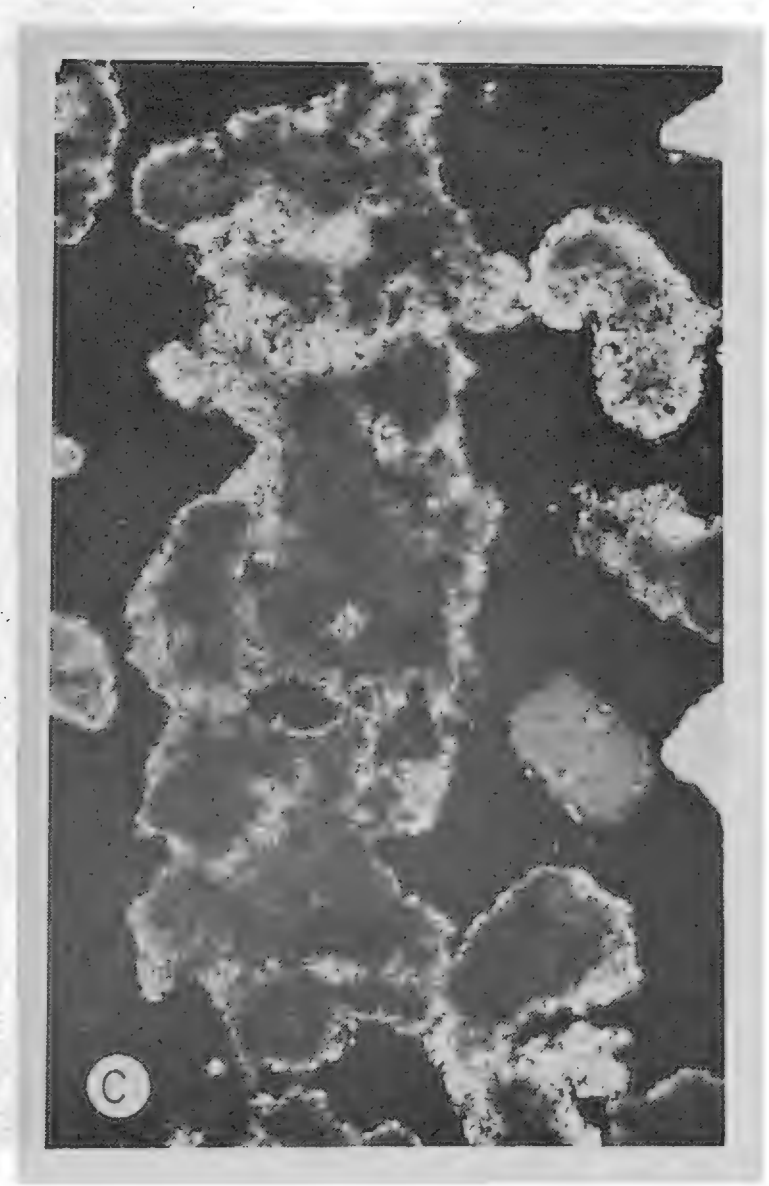
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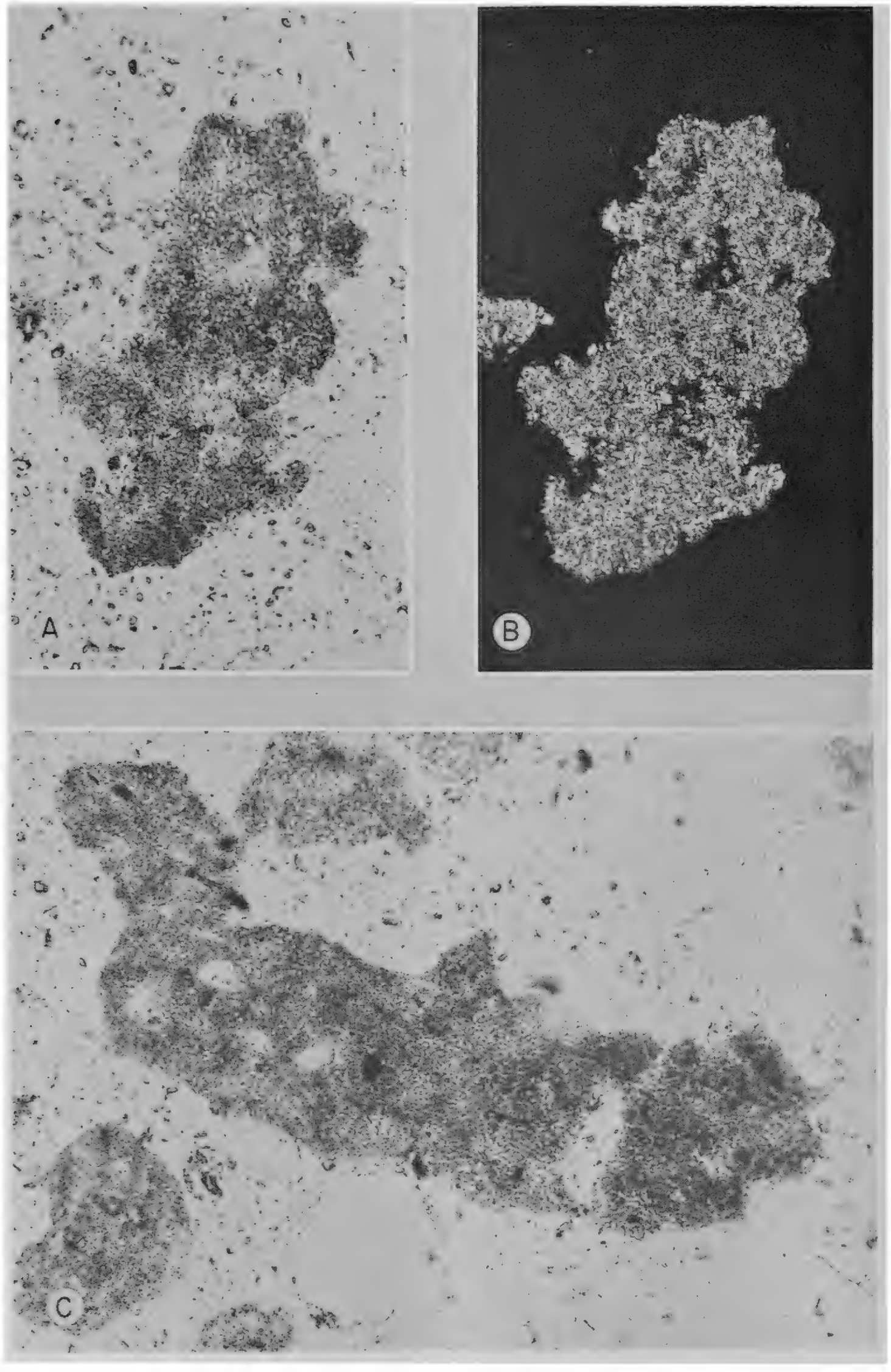
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posed, silt- and clay-size crystals of calcium carbonate, or "micrite" (Folk, 1959). The material that joins small, individual algal micrite grains together to form the larger, flattened grains appears to be identical to the grains themselves (Fig. 3A). Indeed, the process by which the larger grains are produced appears to be one of "coalescence" rather than "cementation."

Decalcification of one of the larger grains with dilute acetic acid resulted in a 52% weight loss and left a flexible replica duplicating the size and shape of the original grain. This replica appeared to consist of mucilaginous organic material with some occluded terrigenous clay. The organic matter and clay are probably the chief contributors to the characteristic cloudy, semi-opaque appearance of thin-sectioned algal micrite grains when viewed in transmitted light.

The color of the grains is brownish-gray in plane polarized light, and dark, yellowish-brown between crossed nicols. X-ray analysis indicates that the calcium carbonate of algal micrite grains is aragonite.

Numerous opaque blebs are present in most algal micrite grains (Fig. 3C). Many of these blebs are circular in outline, have an average diameter of perhaps ten microns, and appear white in reflected light. Their appearance is identical to the remains of boring algae commonly seen in pelecypods, and they probably originate in the same way. Their relative abundance in algal micrite grains may be due to the high organic content of these grains.

Larger, irregularly-shaped, opaque or semi-opaque blebs also are observed in some algal micrite grains. The maximum diameter of these blebs is about forty microns. In reflected light their color ranges from light brown to white. An abundance of identical blebs was observed in the organic portions of plastic-impregnated algal mats, suggesting that the blebs may be organic fragments derived from the mat community. In addition, a few blebs of similar size and shape but having a black, metallic appearance in reflected light were observed. Purdy (1963a) interprets black blebs in Bahamian faecal pellets as iron sulphide resulting from the interaction of hydrogen sulphide with iron. The metallic-appearing blebs in Baffin Bay algal micrite grains may have a similar origin; certainly hydrogen sulphide is present in abundance in the lower zones of the algal mats.

It should be noted that algal micrite grains do not always consist exclusively of cryptocrystalline calcium carbonate. Representatives of all of the grain types of the area are seen to be incorporated in algal micrite grains (Fig. 4A). Most of the smaller algal micrite grains and many of the larger aggregates, however, are devoid of these other, "accessory" grain types (Fig. 4B). Thus, algal micrite grains are basically composed of cryptocrystalline carbonate; and the shell fragments, quartz grains, ooids and coated grains which are often incorporated in them are not essential to the integrity of the grain. In this respect, algal micrite grains differ from Bahamian grapestone, which is defined by Purdy (1963a, p. 344) as ". . . cemented aggregates of skeletal and non-

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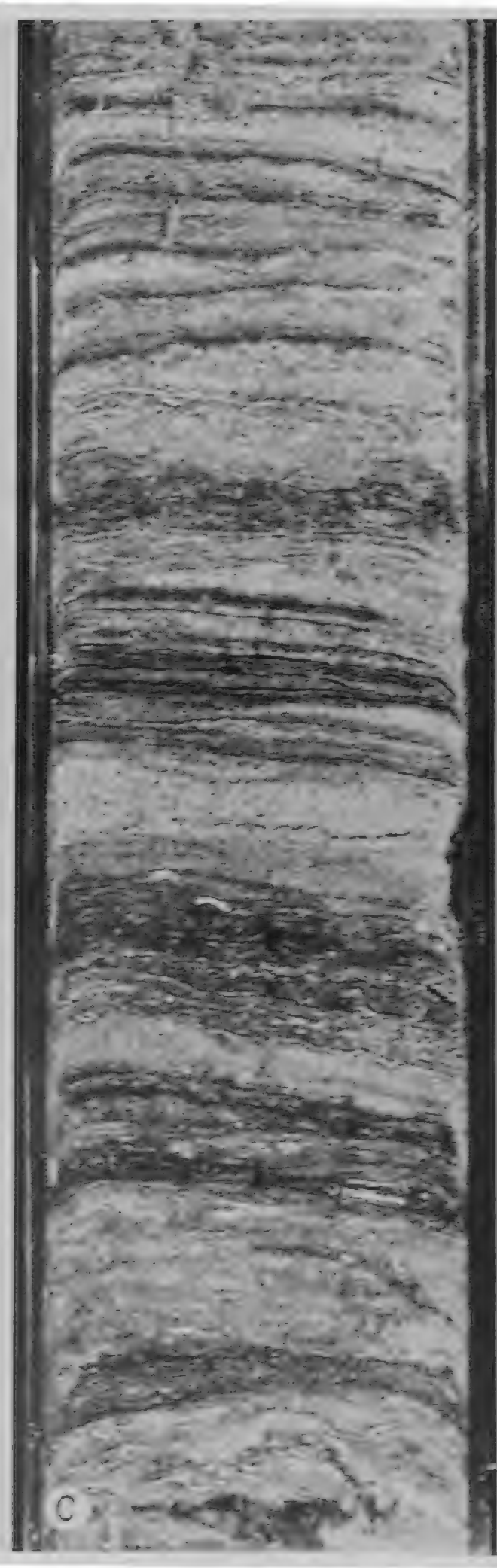
FIG. 3A. Thins-section photomicrograph of an algal micrite grain which is obviously an aggregate of several pre-existing algal micrite grains. In this extremely thin section, it is apparent that the material which cements the original grains together is petrographically identical to the material of the grain themselves. Plane polarized light, ×200. B. Same as Fig. 3-A, but between crossed nicols. Note the pore spaces (black) and the irregular surface of the grain. ×200. C. Thin-section photomicrograph of a large algal micrite grain. Note the elongate, flattened shape and porous interior of this aggregate grain. Note also the numerous opaque blebs, interpreted mainly as organic matter derived from the algal mat community. Plane polarized light, ×160.

A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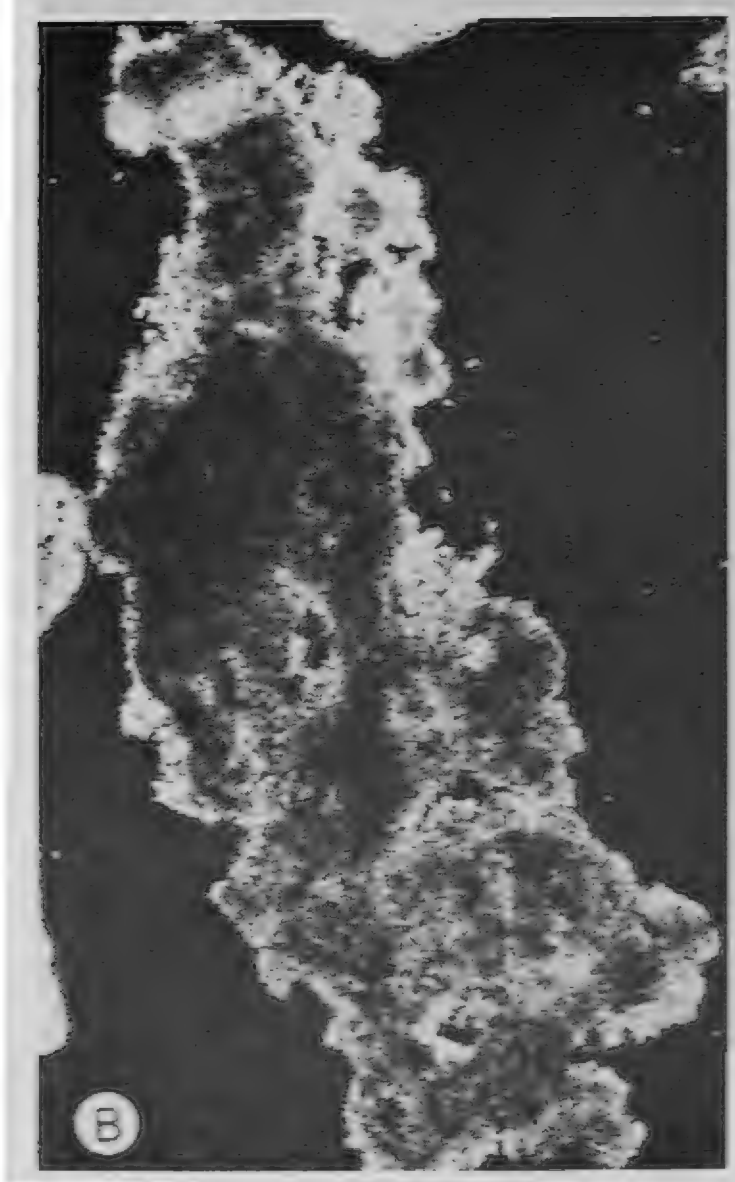
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skeletal grains in which the carbonate cement is restricted largely to the aggregates's periphery."

Distribution of Algal Micrite Grains

The distribution of the various grain types comprising the coarse fraction (larger than one-eighth millimeter) of the Baffin Bay sediments was determined by point-count analysis of 200 thin-sections prepared from plastic-impregnated sediment samples. The most outstanding characteristic of the distribution of algal micrite grains was found to be the coincidence of high volume percentages of these grains with observed algal mat development. In view of this apparent association, it is instructive to consider the influence which the Baffin Bay mats exert on sedimentation.

Sediments of Algal Mats

The fur-like surface of living algal mat is composed of minute algal filaments which extend a short distance up into the overlying water. These filaments carry mucilaginous sheaths (Ginsberg, 1960) which, combined with the intertwining nature of the filaments, enables the mat to trap or fix sediment particles that come in contact with it. As the filaments have motility and positive phototropism in moderate light (Sorensen and Conover, 1962), they are able to move up through a continuous layer of sediment recently deposited on them and re-establish a new surface mat (Ginsburg, 1960). Thus, alternation of sedimentation with algal growth and entrapment results in a laminated sediment (Fig. 4C). The first well-documented report relating laminated sediments such as these to the "stromatolites" commonly found in ancient rocks was Black's (1933) investigation of the algal-laminated sediments of the Bahama Islands. Black and later Ginsburg (1960) and Logan (1961) have related the growth forms of modern stromatolites to their various ancient counterparts. In addition, Logan et al. (1962) have recently completed an exhaustive classification of stromatolites, together with an interpretation of their environmental significance.

Several stromatolite samples from the Baffin Bay area were allowed to dry and then were impregnated under a partial vacuum with a polyester resin. Thin section photomicrographs of these impregnations are illustrated in Figs. 5 through 7. These photographs show that nearly every grain size and grain type found in the Baffin Bay area is incorporated into the stromatolite. In general, algal-rich laminae alternate with sediment-rich laminae, indicating either periodicity of algal growth, periodicity of sedimentation, or most likely, a combination of both. Certainly the sediment supply must fluctuate with changing water level, agitation, and turbidity; and the algal growth, or at least the rate of growth, may be varied by seasonal or other ecological factors, as well as by the rate of sedimentation itself.

The stromatolites of the Baffin Bay complex are completely non-indurated. Logan

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Fig. 4A. Thin-section photomicrograph of an algal micrite grain, showing several detrital quartz grains (white) included in the large, aggregate algal micrite grain. Crossed nicols, ×100. B. Thin-section photomicrograph of a large, complex algal micrite grain composed exclusively of algal micrite. Note the pore spaces (black) and the flattened shape of this rather typical grain. Crossed nicols, ×125. C. Reflected light photograph of a short core of stromatolitic sediment. The lighter-colored layers are composed largely of quartz sand, while the darker layers contain more terrigenous clay and the compressed remains of algal mats. ×1.2.

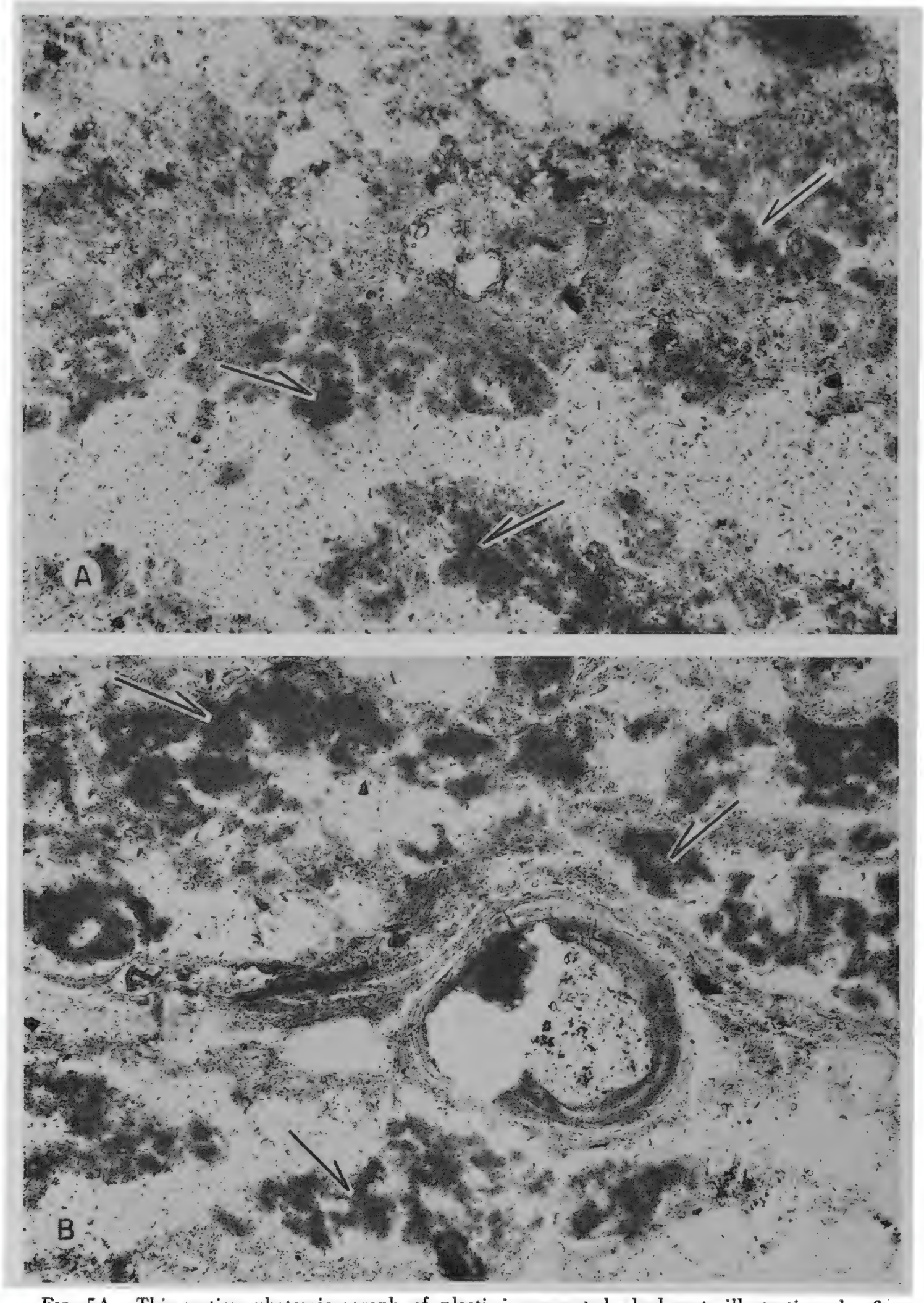

FIG. 5A. Thin-section photomicrograph of plastic-impregnated algal mat, illustrating the first stages in the development of algal micrite grains. At this stage, the algal micrite is difficult to distinguish from the organic material of the mat itself. Arrows point to more obvious areas of algal micrite development. Note the abundant opaque organic fragments within the mat. The large white areas are gaps caused by shrinkage during drying and impregnation. Plane polarized light, ×120. B. Thin-section of mat showing a more advanced stage of algal micrite formation. Distinct micrite grains (arrows) occur among mat laminae. Note the enclosed ooid. Plane polarized light, ×120.

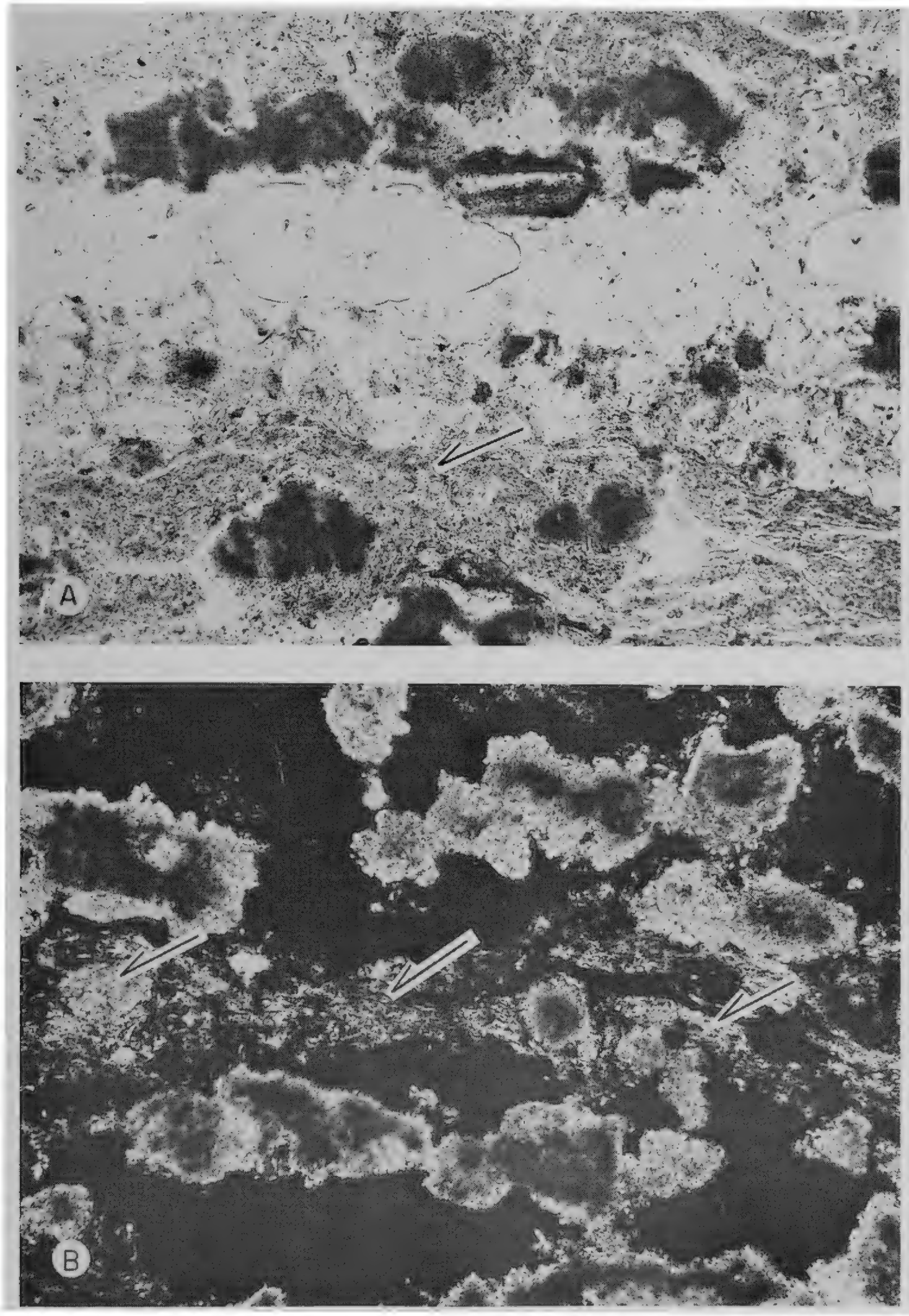

FIG. 6A. Thin-section of algal mat showing discrete algal micrite grains (dark) at two horizons, surrounded by the organic material of the mat (arrow). Plane polarized light, ×140. B. Thin-section of algal mat showing well-developed algal micrite grains within the mat. Note the birefringence of the organic material of the mat (arrows) between crossed nicols. This bright-yellow birefringence is very characteristic, as is the tendency for a given mat lamina to go to extinction as a unit. The black area is pore space resulting from shrinkage of the mat during drying. Crossed nicols, ×120.

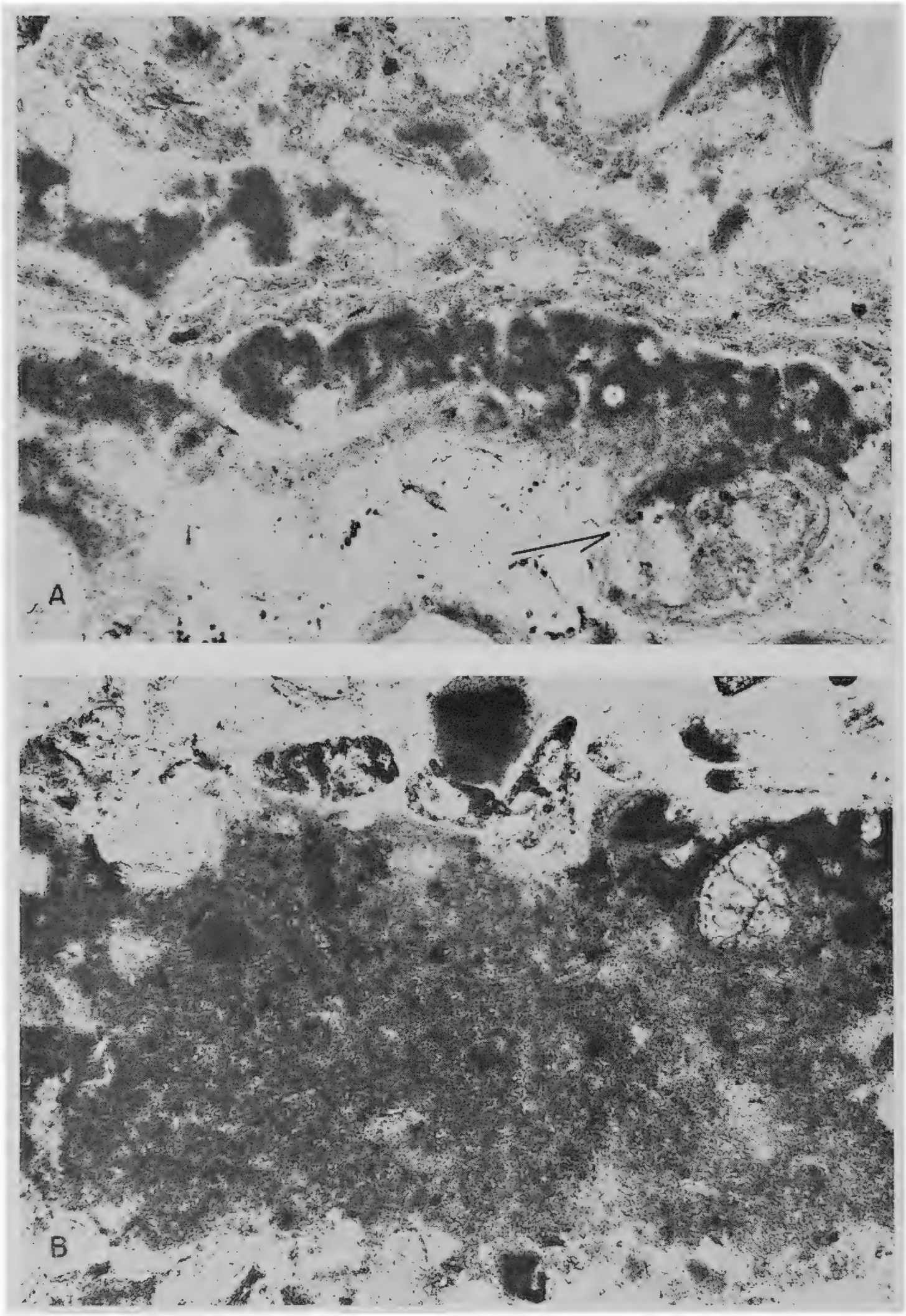

FIG. 7A. Thin-section of algal mat illustrating an advanced stage in the formation of algal micrite. The dark, algal micrite forms a nearly continuous layer across the area of the photograph. Note the partially enclosed foraminifera (arrow). Plane polarizzed light, × 120. B. Thin-section of algal mat showing that the formation of algal micrite has produced a thick, continuous layer of microcrystalline aragonite. Plane polarized light, ×120.

(1961) reported that the discrete, club-shaped or domed algal heads of Shark Bay, Australia, were lithified to varying degrees by a process which he believed to be the usual intertidal precipitation of aragonite. Presumably the process is similar to the formation of beachrock, in which induration is effected by the growth of acicular aragonite crystals into the pore spaces of the rock (Ginsburg, 1953). The acicular crystals have not been observed in the Baffin Bay stromatolites, although they have been reported by Rusnak (1960a) from beachrock in the Baffin Bay area.

Instead, calcium carbonate precipitation of another type is associated with the mats. The grain type resulting from this precipitation has been referred to previously as algal micrite. The origin of algal micrite is of some interest, as this grain type apparently has not been previously described in the literature. Several possible modes of origin will be discussed.

Discussion of the Origin of Algal Micrite

Algal micrite grains certainly do not originate as simple agglomerates of mud, because the mud fraction of Baffin Bay sediments generally contains less than ten percent calcium carbonate (see also Rusnak, 1960a and b), and algal micrite grains contain approximately fifty percent calcium carbonate. Furthermore, algal micrite grains contain little if any terrigenous mud. The non-carbonate portion of algal micrite grains is made up largely of incorporated quartz sand and mucilaginous organic material.

This lack of terrigenous clay in algal micrite grains also rules out the theory that the grains originated as the fecal material of mud-ingesting organisms, or as the fecal material of filter-feeding Lamellibranchs (Jørgensen, 1955). Organisms feeding directly on the organic matter of the mat itself, however, conceivably could produce fecal material essentially devoid of terrigenous clay. Aside from the small clams, *Mulinia lateralis* and *Anomalocardia cuniemeris,* the only macro-invertebrate found in the vicinity of the Baffin Bay mats was a small, red, unidentified worm. This worm was observed only rarely; consequently it seems highly unlikely that its feces could account for the large amounts of algal micrite present in many of the mats. Perhaps the most cogent argument against the theory that algal micrite grains are cemented equivalents of invertebrate fecal material is the observation that the highest abundances of algal micrite grains are found in those stromatolites which are the most regularly laminated, and hence non-burrowed. This indicates that a feces-producing vagile infauna was essentially absent from the algal mat areas when the formation of algal micrite was especially prevalent.

The possibility remains that algal micrite grain formation may be dependent in some way on intertidal exposure. Logan (1961) found that the stromatolites of Shark Bay, Australia, were lithified in the intertidal zone by interstitial precipitation of acicular aragonite in a process similar to the formation of beachrock. The algal micrite of Baffin Bay, however, is decidedly not acicular; therefore it is judged not to be the equivalent of the cement of Shark Bay stromatolites. Inasmuch as the living algal mats of the Baffin Bay complex are restricted to areas where intermittent intertidal exposure is likely to occur, and assuming that algal micrite forms only in association with the mat, the possibility that intertidal exposure is necessary for the formation of algal micrite cannot be entirely negated. Indeed, it seems reasonable that periods of exposure would

allow evaporation to increase the salinity of the water within the mat complex, thus increasing the solubility product and encouraging precipitation.

In considering the possible mode of origin of algal micrite grains, one obvious possibility remains to be considered; namely, that the carbonate is the result of direct precipitation from sea water. Illing (1954) described the cement of Bahamian grapestone as consisting of ". . . finely divided aragonite of varying texture . . . composed of aggregated particles of mud dimensions. From its occurrence, it is clear that it is being precipitated from sea water, yet the particles show no recognizable crystalline shape, and are similar to the material that forms the matrix of the grains themselves" (Illing, 1954, p. 30). In essence, then, Illing finds evidence for the direct precipitation of microcrystalline aragonite from sea water.

The close association of algal micrite grains with well-developed algal mats strongly suggests that the mat or the mat environment in some way influences the formation of the grains. This influence could take a number of forms. For example, the photosynthetic activity of the algae in the upper zones of the mats might initiate calcium carbonate precipitation by extracting carbon dioxide from the water in the immediate vicinity. Eardley (1938) cites this process as one of the causes of precipitation of calcium and magnesium carbonates in the unicellular algal bioherms of Great Salt Lake, Utah. If a similar process is active in the Baffin Bay mats, however, one might expect the precipitated carbonate to occur as crusts around the algal filaments, or to fall as a "rain" of fine crystals on the surface of the mat. Neither of these modes of occurrence was observed in the Baffin Bay mats. Because of the many possible catalytic effects within the mat, however, intuitive expectations as to the form of calcium carbonate precipitation induced by photosynthetic activity are not sufficient to entirely disregard this hypothesis.

Alternatively, decomposition of the abundant organic material in the mats by ammonifying bacteria could result in the production of ammonia and the precipitation of calcium carbonate in the manner described by Purdy (1963b, p. 486).

$$NH_3 + H_2O = NH_4OH \qquad (1)$$

$$2NH_4(OH) + Ca(HCO_3)_2 = (NH_4)_2CO_3 + 2H_2O + CaCO_3 \qquad (2)$$

Purdy cites this or similar reactions as responsible for the aragonite cement of grapestone, fecal pellets and mud aggregates in Bahamian sediments. Of course, this anaerobic bacterial action would take place only in a reducing environment, but the black, oderiferous character of the lower layers of the algal mats indicates that reducing conditions prevail therein (see also Rusnak, 1960a and b). The presence of a reducing environment in the mat is substantiated by the work of Sorensen and Conover (1962, p. 69) who describe a zone of hydrogen sulphide with ". . . an autotrophic purple bacterium . . . and bacteria including *Beggiota* sp." in their zone E, four to ten millimeters below the surface of the algal mats of the Laguna Madre area.

Algal micrite precipitation induced by organic decay might also account for the intimate interrelationship of algal micrite grains to the organic portion of the mat. As seen in thin sections of plastic-impregnated stromatolites, the algal micrite appears to be in a sense "replacing" the original algal material. For example, all gradations can be seen from pure organic mat, through finely-divided mixtures of mat and micrite, to typical algal micrite grains (Figs. 5 through 7). If micrite precipitation is induced by bacterial destruction of the mat, then such a relationship would be expected.

In addition, the discrete nature of individual, globular grains of algal micrite seen

between many algal laminae could be accounted for by precipitation indirectly induced by organic decay. Because a given layer of organic matter in the lower, reducing zones of an algal mat is probably not a homogeneous body, but rather a complex mixture of various types of organic debris, one might expect such a layer to be attacked by bacteria, not evenly and regularly throughout the layer, but preferentially at loci most suitable for bacterial activity. The discreteness of these loci might even be emphasized by rapid reproduction of the bacteria in these initially more favorable micro-environments. As the organic matter in these favorable areas is consumed and "replaced" by algal micrite, the sites of most active bacterial activity would move through the organic layer, enlarging and combining the initially formed grains and resulting in the aggregate texture commonly seen in the large grains. Confinement of this activity to a given layer or layers within the mat would produce the flattened shape so often observed in the larger aggregates. The ultimate result would be an essentially continuous micrite replica of the original layer.

The factors which determine the location of the postulated centers of micrite deposition are unknown, although it may be that certain types of organic material are more favorable than others for bacterial colonization.

Summary

In summary, several hypotheses for the genesis of algal micrite grains have been considered in light of observations made on the nature and occurrence of these grains in the Baffin Bay area and on similar grains in other areas. Although present information does not permit an unequivocal statement as to the exact genesis of these grains, the following interpretation best accounts for the observed facts. The micrite is precipitated as microcrystalline aragonite directly from super-saturated sea water in association with algal mats. The specific chemical reaction is unknown, but inducement of precipitation by anaerobic bacteria involved in the decomposition of the mat's organic matter may be involved. Thus the precipitation may take place in the lower, reducing zones of the mat. Discrete loci of initial micrite precipitation may be related to more favorable areas for bacterial colonization.

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An Annotated Checklist of the Fishes of the Galveston Bay System, Texas[1]

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Abstract

This checklist includes fishes collected from Galveston Bay, Texas, in the course of regularly scheduled sampling operations by the Bureau of Commercial Fisheries during the years 1961–64. All other species known to occur in this bay system are also listed. The annotations, although incomplete in many instances, indicate the relative abundance of each species, as well as its distribution with respect to area, season, and salinity. Such information is based on observations by the author and those recorded in the literature. In all, 162 species represented by 122 genera and 66 families are listed.

Introduction

This checklist is intended to expand present knowledge of the composition and distribution of the first fauna inhabiting Gulf coast estuaries and lagoons. Hoese (1958) noted the need for centralized information of this type for fishes in the Gulf of Mexico, and a similar need has become evident in the case of fish occurring in estuaries and lagoons of the Gulf coast. Much of the existing information on this subject is either recorded in mimeographed reports having limited distribution or is scattered throughout a variety of journals. To provide a more comprehensive listing, I have combined records from all other sources with information (1) furnished by personnel of the Texas Parks and Wildlife Department, and (2) collected over a 4-year period in the Galveston Bay system by personnel of the Bureau of Commercial Fisheries.

Previous Literature

Jordan and Gilbert (1883) presented the first scientific listing of fishes from the Galveston area and included four species from the bay system proper. In 1894, Evermann and Kendall contributed additional species listings, as did Fowler (1945) and Baughman (1950a, 1950b). But it was not until Reid's studies (1955a, 1955b, 1956, 1957) in East Bay that an extensive survey of the fish fauna was presented. Rather elaborate studies have since been conducted by Chambers and Sparks (1959) in the upper (estuarine) portions of the Houston Ship Channel; by Hoese (1959a, 1959b, 1959c) in East and West Bays, the passes, and near the Galveston Jetties; by Renfro (1959a, 1959b) in Upper Galveston and Trinity Bays; by Arnold, Wheeler, and Baxter (1960) in East Lagoon; by Shidler (1960) throughout the bay system; by Pullen (1960, 1961, 1962) in Upper Galveston and Trinity Bays; and by Chin (1961) in Clear Lake.

[1] Contribution No. 198, Bureau of Commercial Fisheries, Galveston, Texas.

Description of the Area

The Galveston Bay system is bounded from east to west on its seaward side by the Bolivar Peninsula, Galveston Island, and Follets Island, and is connected with the Gulf by Rollover Pass, Bolivar Roads, and San Luis Pass (Fig.1) Fresh water enters by way of two major river systems: the Trinity which empties into Trinity Bay and the San Jacinto which empties into the Houston Ship Channel and thence into Upper Gal-

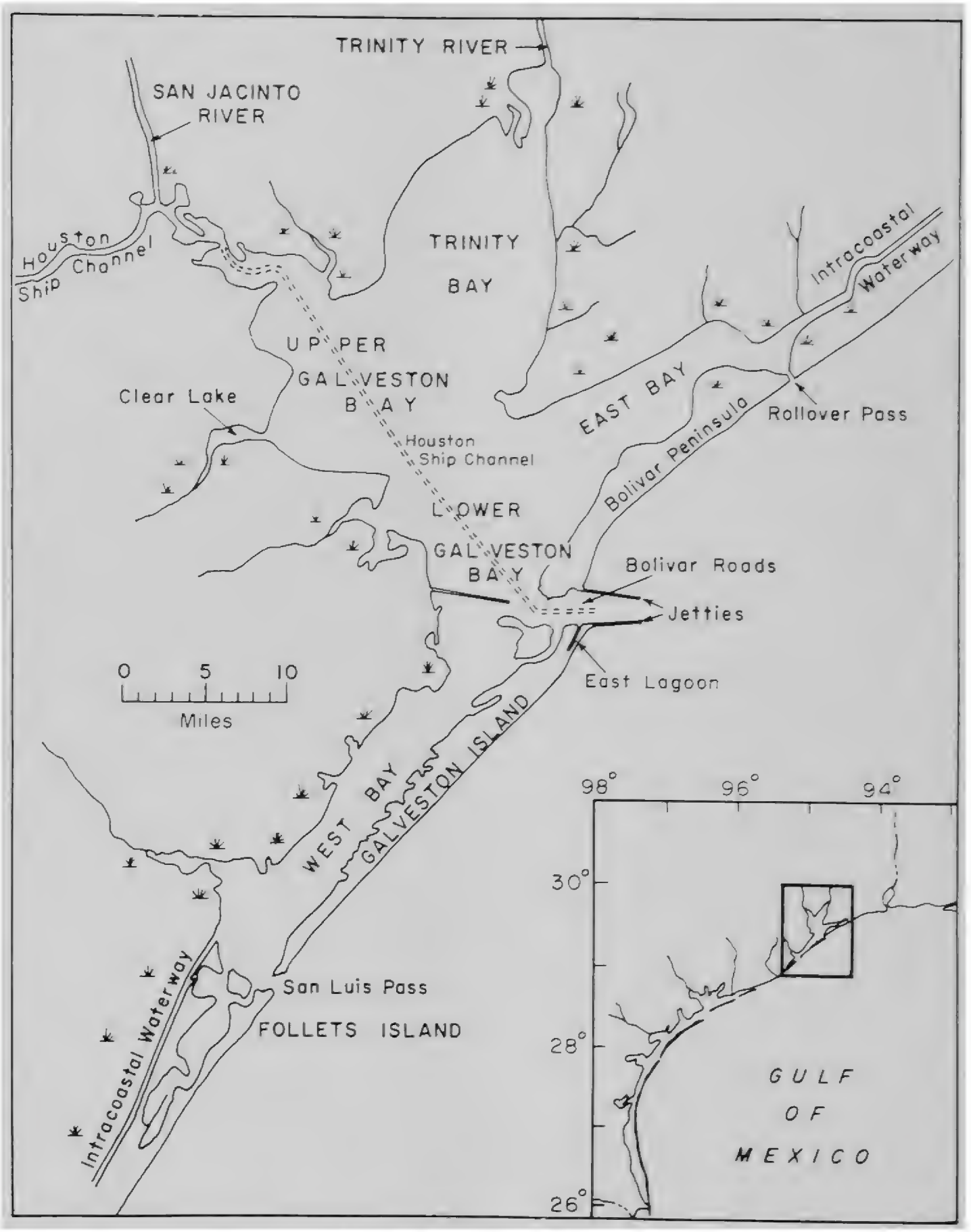

Fig. 1. Map of Galveston Bay.

veston Bay. Additional fresh water is contributed by numerous bayous and creeks as well as by the Intracoastal Waterway which transports runoff from peripheral marsh areas. Comprising an area of some 525 square miles, the system is composed of East Bay, West Bay, Upper and Lower Galveston Bays, and Trinity Bay, along with sundry secondary bays and lakes. The seaward limits of the system with respect to the species included in the following list were arbitrarily placed just inside the passes and jetties. The inland limits were set at the mouths of the San Jacinto and Trinity Rivers and at the east and west entrances of the Intracoastal Waterway. Observations in the near vicinity of the mouths of the numerous bayous and creeks are included.

Presentation of Species

The annotations, although incomplete in many instances, are intended to describe the relative abundance of each species as well as its distribution with respect to area, season, and salinity. Those species collected and/or identified by Bureau of Commercial Fisheries personnel during the years 1961–64 are designated with an asterisk (*). References following annotations include those studies which have contributed to the knowledge of the indicated species. It should be understood that many of the fishes inhabiting the inshore waters of the Gulf of Mexico and the fresh-water rivers and streams which empty into them are only occasional migrants into the bays. No attempt is made to include unreported but likely occurring forms or species whose location has been listed as "Galveston" with no specific reference to the bay system itself.

The fish species are listed according to the American Fisheries Society's "List of Common and Scientific Names of Fishes From the United States and Canada" (Special Publication No. 2, 2nd Ed., 1960). If more recent taxonomic revisions are available, however, the latest nomenclature is used. In all, 162 species represented by 122 genera and 66 families are included. Of these species, 115 were identified from material made available to the author. Information on the remaining 47 was obtained from published reports or from unpublished records of the Texas Parks and Wildlife Department.

Four arbitrary categories are used to indicate relative abundance: rare, uncommon, common, and abundant. A real distribution is described on the basis of seasons and salinity. Where appropriate, self-explantory hydrographic connotations are also included.

The criteria which were used to describe the salinity characteristics of the Galveston Bay system are: extremely low (0–5 ppt), low (5–10 ppt), moderate (10–20 ppt), and high (20–35 ppt). Generally, under average river-flow conditions, extremely low salinity water is restricted to the marshes and bayous of the upper bays and to areas near the mouths of the rivers. Low salinity conditions are normally observed in the upper portions of Trinity, Upper Galveston, and East Bays; whereas, moderate salinity water is usually found in the lower regions of these bays as well as in the greater part of West Bay and the upper part of Lower Galveston Bay. The waters in and immediately adjacent to the jetties and passes normally fall into the high salinity range. A wedge of high salinity water consistently penetrates the bay at the bottom of the Houston Ship Channel, being observed on occasion some 20 nautical miles up the Channel from the Gulf.

Annotated List

CLASS CHONDRICHTHYES—Cartilaginous Fishes

ORDER SQUALIFORMES (Selachii)

Family Carcharhinidae—Requiem sharks

Carcharhinus leucas (Muller and Henle)—Bull shark

Rare, an occasional summer resident in high salinity waters. Renfro (1959a); Pullen (1960, 1962).

C. limbatus (Muller and Henle)—Blacktip shark

Rare, an occasional summer resident in high salinity waters. Reid (1955a, 1955b, 1956, 1957).

Scoliodon terraenovae (Richardson)—Atlantic sharpnose shark

Rare, one specimen taken from West Bay in the summer of 1961 was identified by biologists of the Texas Game and Fish Commission (personal communication).

Family Sphyrnidae—Hammerhead sharks

Sphyrna lewini (Griffith)—Scalloped hammerhead shark*

Rare, a summer migrant usually present in high salinity waters.

S. tiburo (Linnaeus)—Bonnethead*

Uncommon, a summer migrant usually present in high salinity waters.

ORDER RAJIFORMES (BATOIDEI)

Family Pristidae—Sawfishes

Pristis pectinatus Latham—Smalltooth sawfish*

Rare, both young and adults have been caught in waters of high salinity.

Family Rajidae—Skates

Raja texana Chandler—Roundell skate*

Rare, one specimen was collected in East Bay in the summer of 1963.

Family Dasyatidae—Stingrays

Dasyatis americana Hildebrand and Schroeder—Southern stingray*

Uncommon in this bay system.

D. sabina (LeSueur)—Atlantic stingray*

This is the common stingray of the area and is abundant during the spring and summer in both moderate and high salinity waters. Reid (1955a, 1955b, 1956, 1957); Hoese (1959a); Renfro (1959b); Shidler (1960); Pullen (1960, 1962).

D. sayi (LeSueur)—Bluntnose stingray *

Rare, one specimen was collected in East Bay in the spring of 1963.

Gymnura micrura (Bloch and Schneider)—Smooth butterfly ray*

Rare, apparently restricted to high salinity waters. Hoese (1959b).

Family Myliobatidae—Eagle rays

Aetobatus narinari (Euphrasen)—Spotted eagle ray*

Rare, collected from West Bay in August 1964 by a local fisherman.

Rhinoptera bonasus (Mitchill)—Cownose ray

Although uncommon during most of the year, there is evidence that large schools of the cownose ray spawn in the bay system in late summer. Pullen (1960, 1962).

CLASS OSTEICHTHYES—Bony Fishes

ORDER ACIPENSERIFORMES (CHONDROSTEI)

Family Polyodontidae—Paddlefishes

Polyodon spathula (Walbaum)—Paddlefish*

Rare, found near shore between the Galveston jetties in 1960 by a local resident. The fish, a fresh-water species, was alive but very sluggish when captured.

ODRER SEMIONOTIFORMES (PROTOSPONDYLI AND GINGLYMODI)

Family Lepisosteidae—Gars

Lepisosteus oculatus (Winchell)—Spotted gar*

Common during all seasons, inhabiting extremely low to low salinity waters of the bayous and marshes. Reid (1955b, 1956, 1957) as *L. productus* Cope; Chambers and Sparks (1959) as *L. productus* (Cope); Chin (1961).

L. osseus (Linnaeus)—Longnose gar*

Uncommon, accasionally entering the extremely low to low salinity waters of the bayous and marshes. Renfro (1959a, 1959b); Pullen (1960, 1962); Renfro (1963).

L. platostomus Rafinesque—Shortnose gar

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

L. spatula (Lacépède)—Alligator gar*

Common from spring through fall in waters of low to moderate salinity. Baughman (1950a); Reid (1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler, and Baxter (1960); Pullen (1960, 1962); Chin (1961).

ORDER CLUPEIFORMES (ISOSPONDYLI)

Family Elopidae—Tarpons

Elops saurus Linnaeus—Ladyfish*

Common during the summer in moderate to high salinity waters. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Renfro (1959a); Arnold, Wheeler, and Baxter (1960); Pullen (1960, 1962).

Megalops atlantica Valenciennes—Tarpon*

Uncommon, during the summer schools of tarpon occasionally enter high salinity waters. Baughman (1950a) as *Tarpon atlanticus* Cuvier and Valenciennes.

Family Albulidae—Bonefishes

Albula vulpes (Linnaeus)—Bonefish

Baughman (1950a) reports a record of this species from Galveston Bay, but as it is a leptocephalid, he presumes it might have been *Elops saurus* Linnaeus.

Family Clupeidae—Herrings

Alosa charysochloris (Rafinesque)—Skipjack herring*

Uncommon, this fresh-water species occasionally frequents extremely low to low salinity waters. Pullen (1962).

Brevoortia gunteri Hildebrand—Finescale menhaden*

Uncommon, a marine species seldom found in the bays.

B. patronus Goode—Largescale menhaden*

Abundant, found year round throughout the bay system. Fowler (1945) as

B. tyranus patronus Goode; Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1961, 1962); Shidler (1960); Chin (1961); Renfro (1963); Stevens (1963b).

Dorosoma cepedianum (LeSueur)—Gizzard shad*

Common from spring through fall, residing predominantly in extremely low to low salinity waters. Jordan and Gilbert (1883); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1961, 1962).

D. petenese (Günther)—Threadfin shad*

Common in the summer, fall, and winter in extremely low to moderate salinity waters. Fowler (1945) as *Signalosa patensis atchafalayae* Evermann and Kendall; Reid (1955a, 1955b, 1956, 1957) as *S. petenesis* Günther; Chambers and Sparks (1959); Renfro (1959a); Chin (1961); Pullen (1960, 1961, 1962).

Harengula pensacolae Goode and Bean—Scaled sardine*

Common during late summer and early fall near the jetties and passes. Reid (1955b, 1956, 1957) as *H. p. pensacolae* Goode and Bean; Arnold, Wheeler and Baxton (1960).

Opisthonema oglinum (LeSueur)—Atlantic threadfin herring*

Uncommon, occasionally present in waters of high salinity. Arnold, Wheeler and Baxter (1960).

Sardinella anchovia Valenciennes—Spanish sardine

Rare. Fowler (1945).

Family Engraulidae—Anchovies

Anchoa hepsetus (Linnaeus)—Striped anchovy*

Uncommon, occasionally present in waters of high salinity. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

A. mitchilli (Valenciennes)—Bay anchovy*

Abundant, found in large numbers during all seasons throughout the bay system. Jordan and Gilbert (1883) as *Stolephorus mitchilli* (Cuvier and Valenciennes); Fowler (1945) as *A. m. mitchilli* (Valenciennes); Reid (1955a, 1955b, 1956, 1957) as *A. m. diaphana* Hildebrand; Chambers and Sparks (1959) as *A. mitchilli* Hildebrand; Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960) as *A. m. diaphana* (Cuvier and Valenciennes); Pullen (1960) as *A. m. diaphana* Hildebrand; Chin (1961) as *A. m. diaphana* Hildebrand; Pullen (1961, 1962); Renfro (1963); Stevens (1963b).

ORDER MYCTOPHIFORMES (INIOMI)

Family Syndontidae—Lizardfishes

Synodus foetens (Linnaeus)—Inshore lizardfish*

Common, found during spring, summer, and fall in high salinity waters. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

ORDER CYPRINFORMES (OSTARIOPHYSI)

Family Cyprinidae—Minnows and carps

Campostoma anomalum (Rafinesque)—Stoneroller

Rare. Fowler (1945).

Cyprinus carpio Linnaeus—Carp*

Rare, found in extremely low salinity water near the mouths of the rivers and bayous. Chambers and Sparks (1959); Pullen (1960, 1962).

Notropis sp.—Shiner

Rare, predominantly a fresh-water species. Pullen (1962).

Family Catostomidae—Suckers

Carpiodes carpio (Rafinesque)—River carpsucker*

Rare, found in waters of low salinity near the mouths of the rivers and bayous. Renfro (1959a, 1959c).

Ictiobus bubalus (Rafinesque)—Smallmouth buffalo*

Rare, restricted to waters of low salinity near the mouths of the rivers and bayous. Chambers and Sparks (1959); Pullen (1960, 1962).

Family Ariidae—Sea Catfishes

Bagre marinus (Mitchill)—Gafftopsail catfish*

Abundant from summer through fall in low to high salinity waters. Fowler (1945) as *Ailurichthys marinus* (Mitchill); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Galeichthys felis (Linnaeus)—Sea catfish*

Abundant from spring through fall in moderate to high salinity waters. Fowler (1945) as *Trachysurus felis* (Linnaeus); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Family Ictaluridae—Freshwater catfishes

Ictalurus furcatus (LeSueur)—Blue catfish*

Rare, found in low salinity water near the mouths of the rivers and bayous. Renfro (1959a, 1959c); Pullen (1960, 1961, 1962) as *I. f. furcatus* (LeSueur).

I. melas (Rafinesque)—Black bullhead

Rare, found in low salinity water near the mouths of the rivers and bayous. Chambers and Sparks (1959) as *Ameirus melas* (Girard); Renfro (1959a); Pullen (1960, 1962) as *Amerius mela* Rafinesque.

I. natalis (LeSueur)—Yellow bullhead

Rare, found in low salinity water near the mouths of the rivers and bayous. Pullen (1962).

I. punctatus (Rafinesque)—Channel catfish*

Rare, found in low salinity water near the mouths of the rivers and bayous. Renfro (1959a); Pullen (1960) as *I. p. punctatus* (Rafinesque); Pullen (1962).

ORDER ANGUILLIFORMES (APODES)

Family Anguillidae—Freshwater eel

Anguilla rostrata (LeSueur)—American eel.

Rare. Reported near the mouth of the Trinity River in data collected for a class project by the Department of Wildlife Management, Texas A & M University.

Family Muraenidae—Morays

Gymnothorax moringa (Cuvier)—Spotted moray*

Rare, found near the jetties and passes. Arnold, Wheeler and Baxter (1960) as *G. ocellatus* Agassiz.

Family Ophichthidae—Snake Eels

Myrophis punctatus Lütken—Speckled worm eel*

Common. This is the most abundant eel in the bay system although not collected in large numbers, it is distributed throughout the bay. Reid (1955b, 1956, 1957); Renfro (1959a, 1959b, 1963); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

Mystriophis mordax (Poey)—Snapper eel

Rare, apparently restricted to high salinity waters. Reid (1957); Arnold, Wheeler and Baxter (1960).

Ophichthus gomesi (Castelnau)—Shrimp eel*

Uncommon, found occasionally in moderate to high salinity waters. Renfro (1959a).

ORDER BELONIFORMES (SYNENTOGNATHI)

Family Belonidae—Needlefishes

Strongylura marina (Walbaum)—Atlantic needlefish*

Common in waters of high salinity. Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

Family Hemiramphidae—Halfbeaks

Hyporhamphus unifasciatus (Ranzani)—Halfbeak

Uncommon, found occasionally from spring through summer near the jetties. Arnold, Wheeler and Baxter (1960).

Family Exocoetidae—Flyingfishes

Prognichthys rondeleti (Valenciennes)—Blackwing flyingfish

Rare. Baughman (1950a) as *Danichthys rondeletii* (Cuvier and Valenciennes). Biologists of the Texas Parks and Wildlife Department collected this species in Upper Galveston Bay in the spring of 1964 (personal communication).

ORDER CYPRINODONTIFORMES (MICROYPRINI)

Family Cyprinodontidae—Killifishes

Adinia xenica (Jordan and Gilbert)—Diamond killifish*

Uncommon, but apparently distributed throughout the bay system in shallow water grass flats. Reid (1956); Simpson and Gunter (1956) as *A. multifasciata* Girard; Reid (1957); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

Cyprinodon variegatus Lacépède—Sheepshead minnow*

Common in shallow waters throughout the bay system. Evermann and Kendall (1894); Reid (1955a, 1955b, 1956) as *C. v. variegatus* Lacépède; Simpson and Gunter (1956); Reid (1957) as *C. v. variegatus*; Chambers and Sparks (1959); Arnold, Wheeler and Baxter (1960) as *C. v. variegatus* Lacépède; Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Fundulus chrysotus (Günther)—Golden topminnow

Rare, apparently restricted to waters of extremely low salinity. Baughmann (1950a).

F. grandis Baird and Girard—Gulf killifish*

Common year round in shallow water areas. Evermann and Kendall (1894) as *F. pallidus* Evermann; Fowler (1945) as *F. heteroclitus grandis* Baird and Girard; Reid (1955a, 1955b, 1956) as *F. g. grandis* Baird and Girard; Simpson and Gunter (1956); Reid (1957) as *F. g. grandis* Baird and Girard; Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

F. jenkinsi (Evermann)—Saltmarsh topminnow

Rare, apparently restricted to extremely low to moderate salinity waters near the mouths of the bayous and creeks. Evermann and Kendall (1894) as *Zygonectes jenkinsi* Evermann; Simpson and Gunter (1956).

F. pulvereus (Evermann)—Bayou killifish

Rare, apparently restricted to extremely low to moderate salinity waters near the mouths of the bayous and creeks. Gunter and Knapp (1951); Simpson and Gunter (1956); Pullen (1962).

F. similis (Baird and Girard)—Longnose killifish*

Common throughout the year in shallow waters. Fowler (1945); Reid (1955b, 1956, 1957); Simpson and Gunter (1956); Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

Lucania parva (Baird and Girard)—Rainwater killifish*

Common to the waters of shallows and flats. Simpson and Gunter (1956); Pullen (1960, 1962).

Family Poeciliidae—Livebearers

Gambusia affinis (Baird and Girard)—Mosquitofish

Common in waters near shore and in marshy flats. Simpson and Gunter (1956); Renfro (1959a, 1959b); Pullen (1960, 1962).

Mollienesia latipinna LeSueur—Sailfin molly*

Common year round in the waters of shallows and flats. Reid (1955b, 1956); Simpson and Gunter (1956); Reid (1957); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1961, 1962).

ORDER GADIFORMES (ANACANTHINI)

Family Gadidae—Hakes

Urophycis floridanus (Bean and Dresel)—Southern hake*

Uncommon, found in small numbers during the spring, fall, and winter. Fowler (1945); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Pullen (1960); Chin (1961).

ORDER GASTEROSTEIFORMES (THORACOSTEI + HEMIBRANCHII + LOPHOBRANCHII + SOLENICHTHYES)

Family Syngnathidae—Pipefishes and seahorses

Hippocampus erectus Perry—Spotted seahorse*

Rare, found in waters of high salinity near floating seaweed and in shallow grass flats.

H. zosterae Jordan and Gilbert—Dwarf seahorse*

Rare, found in waters of high salinity near floating seaweed and in shallow grass flats.

Syngnathus floridae (Jordan and Gilbert)—Dusky pipefish*

Rare, inhabiting high salinity waters of grassy flats. Hoese (1959b); Renfro (1959a); Pullen (1960, 1962).

S. louisianae Günther—Chain pipefish

Rare, reported from East Bay. Reid (1955a, 1955b, 1956, 1957).

S. scovelli (Evermann and Kendall)—Gulf pipefish*

Common in moderate to high salinity waters in areas of vegetation. Hoese (1959b); Renfro (1959a); Chin (1961); Pullen (1962).

ORDER PERCOPSIFORMES (SALMOPERCAE)

Family Aphredoderidae—Pirate perches

Aphredoderus sayanus (Gilliams)—Pirate perch

Rare, predominantly a fresh-water species. Pullen (1960, 1962) as *A. s. gibbosus* (LeSueur).

ORDER PERCIFORMES (PERCOMORPHI, ACANTHOPTERYGII)

Family Serranidae—Sea basses

Centropristes philadelphicus (Linnaeus)—Rock sea bass*

Rare, found in waters of high salinity. Hoese (1959b); Renfro (1959a); Pullen (1960, 1961, 1962).

Epinephelus itajara (Lichtenstein)—Jewfish

Rare, found predominantly near the jetties. Hoese (1959a) as *Promicrops itiaria* (Lichtenstein).

E. nigritus (Holbrook)—Warsaw grouper*

Rare, collected in West Bay in January 1963 by a local fisherman.

Roccus chrysops (Rafiinesque)—White bass

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

R. mississippiensis (Jordan and Eigenmann)—Yellow bass

Rare, a fresh-water species which occasionally ventures into low salinity waters. Chambers and Sparks (1959); Renfro (1959a, 1959c).

Family Lobotidae—Tripletails

Lobotes surinamensis (Bloch)—Tripletail

Uncommon. Reid (1955a, 1955b, 1956, 1957); Pullen (1962).

Family Lutjanidae—Snappers

Lutjanus apodus (Walbaum)—Schoolmaster

Rare, collected in 1963 in East Bay by personnel of the Texas Parks and Wildlife Department (personal communication).

L. griseus (Linnaeus)—Gray snapper

Rare, reported from West Bay in 1963 by personnel of the Texas Parks and Wildlife Department (personal communication).

L. synagris (Linnaeus)—Lane snapper*

Uncommon, frequenting waters of high salinity. Arnold, Wheeler and Baxter (1960).

Family Centrarchidae—Sunfishes

Chaenobryttus gulosus (Cuvier)—Warmouth*

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Chambers and Sparks (1959); Renfro (1959a); Pullen (1960, 1962).

Lepomis macrochirus Rafinesque—Bluegill*

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Pullen (1962).

L. microlophus (Günther)—Redear sunfish

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Chambers and Sparks (1959); Pullen (1960, 1962).

Pomoxis annularis Rafinesque—White crappie*

Rare, a fresh-water species which occasionally ventures into low salinity waters during periods of fresh-water discharge from the rivers and bayous. Renfro (1959a, 1959c); Pullen (1960, 1962).

P. nigromaculatus (LeSueur)—Black crappie*

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

Family Percidae—Perches

Etheostoma lepidum (Baird and Girard)—Greenthroat darter

Fowler (1945) reported this species as *Poecilichthys lepidus* (Baird and Girard), however, Hubbs (1954) notes that Fowler's record is based on *Etheostoma spectabile* Agassiz which would not be expected from the brackish water on Galveston Island.

Family Pomatomidae—Bluefishes

Pomatomus saltatrix (Linnaeus)—Bluefish *

Found in large schools during the summer in high salinity waters. Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1962).

Family Rachycentridae—Cobias

Rachycentron canadum (Linnaeus)—Cobia*

Rare, young are found occasionally during the summer in high salinity waters.

Family Carangidae—Jacks and Pompanos

Caranx crysos (Mitchill)—Blue runner

Rare, reported from Lower Galveston Bay in 1963 by the Texas Parks and Wildlife Department (personal communication).

C. hippos (Linnaeus)—Crevalle jack*

Common during the warmer months throughout the bay system. Reid (1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960, 1962).

C. latus Agassiz—Horse-eye jack

Rare, specimens of this jack were found in Upper Galveston Bay in extremely low salinity water. Pullen (1962).

Cholroscombrus chrysurus (Linnaeus)—Bumper*

Common, found during the warmer months in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Pullen (1960, 1962).

Hemicaranx amblyrhynchus (Cuvier)—Bluntnose jack*

Uncommon, found during the warmer months in moderate to high salinity waters. Reid (1955b, 1956, 1957) as *H. amblyrhynchus* (Cuvier and Valenciennes).

Oligoplites saurus (Bloch and Schneider)—Leatherjacket*

Common during the warmer months in high salinity waters of shallow grassy flats. Reid (1955b, 1956); Hoese (1959b); Renfro (1959a); Arnold, Wheeler, and Baxter (1960); Shidler (1960); Pullen (1960, 1962).

Selene vomer (Linnaeus)—Lookdown*

Uncommon, occasionally frequenting high salinity waters. Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960).

Seriola falcata Valenciennes—Almaco jack*

Uncommon, found during the summer near the jetties. This species has not previously been reported from Texas.

Trachinotus carolinus (Linnaeus)—Pompano*

Uncommon, found occasionally during the warmer months in high salinity waters. Reid (1956, 1957); Renfro (1959a); Arnold, Wheeler and Baxter (1960).

Vomer setapinnis (Mitchill)—Atlantic moonfish*

Uncommon, found occasionally during the warmer months in moderate to high salinity waters. Hoese (1959b); Renfro (1959a); Shidler (1960); Pullen (1960, 1962).

Family Coryphaenidae—Dolphins

Coryphaena hippurus Linnaeus—Dolphin

Rare, predominantly a marine species. Arnold, Wheeler and Baxter (1960).

Family Gerridae—Mojarras

Eucinostomus gula (Quoy and Gaimard)—Silver jenny*

Uncommon, found during the warmer months in high salinity waters of shallow vegetated areas. *Eucinostomus* sp. reported by Reid (1955b, 1956) is probably this species; *Eucinostomus* sp. reported by Hoese (1959b) is probably this species; Renfro (1959a); Arnold, Wheeler and Baxter (1960).

Family Pomadyasyidae—Grunts

Orthopristis chrysopterus (Linnaeus) Pigfish*

Common, found during the warmer months in high salinity waters. Fowler (1945); Reid (1955b, 1956); Hoese (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963b).

Family Sciaenidae—Drums

Aplodinotus grunniens Rafinesque—Fresh-water drum

Rare, predominantly a fresh-water species. Chambers and Sparks (1959).

Bairdiella chrysura (Lacépède)—Silver perch*

Common from spring through fall throughout the bay system. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Cynoscion arenarius Ginsburg—Sand seatrout*

Abundant all year throughout the bay system, but present in greatest numbers during the warmer months. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

C. nebulosus (Cuvier)—Spotted seatrout*

Abundant all year throughout the bay system, but present in greatest numbers during the warmer months. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b, 1963); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

C. nothus (Holbrook)—Silver seatrout*

Rare, appearing occasionally in high salinity waters. Fowler (1945); Hoese (1959b).

Larimus fasciatus Holbrook—Banded drum*

Uncommon, found in small numbers during all seasons in high salinity waters. Reid (1956, 1957); Chambers and Sparks (1959); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1962).

Leiostomus xanthurus Lacépède—Spot*

Abundant during the warmer months throughout the bay system. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b, 1959c); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Menticirrhus americanus (Linnaeus)—Southern kingfish*

Common throughout the year in moderate to high salinity waters. Fowler (1945); Reid (1956, 1957); Renfro (1959a); Shidler (1960); Pullen (1960, 1961, 1962).

M. littoralis (Holbrook)—Gulf kingfish

Rare, predominantly a marine species. Reid (1956, 1957).

Micropogon undulatus (Linnaeus)—Atlantic croaker*

Abundant all year throughout the bay system. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b, 1959c); Renfro (1959a, 1959b, 1963); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962); Stevens (1963a, 1963b).

Pogonias cromis (Linnaeus)—Black drum*

Abundant throughout the year in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959a,

1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

Sciaenops ocellata (Linnaeus)—Red drum*

Abundant throughout the year in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b, 1959c); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

Stellifer lanceolatus (Holbrook)—Star drum*

Abundant throughout the year in moderate to high salinity waters, but found predominantly in the deeper waters of the channels. Fowler (1945); Reid (1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Family Sparidae—Porgies

Archosargus probatocephalus (Walbaum)—Sheepshead*

Common all year in moderate to high salinity waters. Reid (1955b, 1956, 1957) as *A. oviceps* Ginsburg; Hoese (1959a, 1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

Lagodon rhomboides (Linnaeus)—Pinfish*

Common all year in moderate to high salinity waters. Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959a, 1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963b).

Family Ephippidae—Spadefishes

Chaetodipterus faber (Broussonet)—Atlantic spadefish*

Common during the warmer months in high salinity waters. Fowler (1945); Reid (1955b, 1956, 1957); Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961).

Family Trichiuridae—Cutlassfishes

Trichiurus lepturus Linnaeus—Atlantic cutlassfish*

Common during the warmer months in moderate to high salinity waters. Reid (1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Pullen (1960, 1961).

Family Scombridae—Mackerels

Scomberomorus maculatus (Mitchell)—Spanish mackerel*

Uncommon, found occasionally during the summer in moderate to high salinity waters. Reid (1956, 1957); Renfro (1959a); Pullen (1960); Shidler (1960).

Family Eleotridae—Sleepers

Dormitator maculatus (Bloch)—Fat sleeper

Uncommon, a fresh-water species whose range is extended throughout the bay system during periods of fresh-water flooding. Evermann and Kendall (1894); Chambers and Sparks (1959); Arnold, Wheeler and Baxter (1960); Pullen (1962).

Family Gobiidae—Gobies

Evorthodus lyricus (Girard)—Lyre goby

Rare. Jordan and Gilbert (1883) as *Gobius lyricus* (Girard); Fowler (1945) as *Gobionellus lyricus* (Girard); Arnold, Wheeler and Baxter (1960).

Gobioides broussonneti Lacépède—Violet goby*

Uncommon, residing primarily in shallow, low salinity waters of lakes and flats. Chambers and Sparks (1959); Renfro (1959a); Chin (1961); Pullen (1962).

Gobionellus boleosoma (Jordan and Gilbert)—Darter goby*

Uncommon, found occasionally in waters of low salinity. Reid (1956, 1957); Hoese (1959a); Renfro (1959a); Pullen (1960, 1962).

G. hastatus Girard—Sharptail goby *

Uncommon, found scattered throughout the bay system, but most abundant in waters of high salinity. Fowler (1945) as *G. h. hastatus* Girard; Renfro (1959a); Arnold, Wheeler and Baxter (1960); Pullen (1960); Shidler (1960) as *G. oceanicus*; Pullen (1961) as *Gobius hastatus*; Pullen (1962).

G. shufeldti (Jordan and Evermann)—Freshwater goby

Rare, apparently restricted to waters of low salinity. Chambers and Sparks (1959); Chin (1961).

Gobiosoma bosci (Lacépède)—Naked goby*

Common, found all year throughout the bay system, but most abundant in the shallow lakes and flats. Hoese (1959a); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960) as *G. molestum* Girrard; Shidler (1960); Chin (1961); Pullen (1960, 1962).

G. robustum Ginsburg—Code goby

Rare, collected by Hinton D. Hoese in grass flats in lower West Bay (personal communication).

Microgobius gulosus (Girard)—Clown goby*

Common, residing year round throughout the bay system, but most abundant in the waters of shallow lakes and flats. Pullen (1960, 1962).

M. thalassinus (Jordan and Gilbert)—Green goby*

Uncommon, found occasionally in the waters of the shallows and flats. Fowler (1945).

Family Scorpaenidae—Scorpionfishes

Scorpaena calcarata Goode and Bean—Smoothhead scorpionfish*

Rare, apparently restricted to deep waters of high salinity.

Family Triglidae—Searobins

Prionotus scitulus Jordan and Gilbert—Leopard searobin*

Uncommon, apparently restricted to high salinity waters.

P. tribulus Cuvier—Bighead searobin*

Common, found during all seasons throughout the bay system. Fowler (1945); Reid (1956) as *P. t. crassiceps* Ginsburg; Renfro (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Family Uranoscopidae—Stargazers

Astrocopus γ-graecum (Suvier)—Southern stargazer*

Rare, this species is occasionally found in the deeper high salinity waters of the bay system. Fowler (1945); Renfro (1959a); Chin (1961).

Family Clinidae—Clinids

Labrisomus nuchipinnis (Quoy and Gaimard)—Hairy blenny.

Rare, apparently restricted to waters of high salinity. Hoese (1959a); Arnold, Wheeler and Baxter (1960).

Family Blenniidae—Combtooth blennies

Chasmodes bosquianus (Lacépède)—Striped blenny*

Common in waters of high salinity. Hoese (1959a); Shidler (1960); Pullen (1962).

Hypsoblennius ionthas (Jordan and Gilbert)—Freckled blenny*

Common in high salinity waters near oyster reefs and around the jetties. Jordan and Gilbert (1883) as *Isesthes scrutater* sp. nov.; Hoese (1959a); Hofstetter (1959); Pullen (1960, 1962).

Family Ophidiidae—Cusk-eels

Ophidion welshi (Nichols and Breder)—Crested cusk-eel*

Uncommon, found occasionally in high salinity waters.

Rissola marginata (De Kay)—Striped cusk-eel*

Uncommon, found in moderate to high salinity waters. Pullen (1960, 1962).

Family Stromateidae—Butterfishes

Peprilus paru (Linnaeus)—Northern harvestfish*

Common during the warmer months in waters of moderate to high salinity. Fowler (1945); Reid (1955b, 1956, 1957); Renfro (1959a); Pullen (1960, 1962).

Poronotus burti (Fowler)—Butterfish* (*see* Collete, 1963)

Common during the warmer months in waters of high salinity. Fowler (1945) as *Peprilus burti* Fowler; Renfro (1959a) as *Poronotus triacanthus* (Peck); Pullen (1960, 1962) as *Poronotus triacanthus* (Peck).

Family Mugilidae—Mullets

Mugil cephalus Linnaeus—Striped mullet*

Abundant all year throughout the bay system. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962); Stevens (1963b).

M. curema Valenciennes—White mullet

Uncommon, apparently restricted to high salinity waters. Reid (1955a, 1955b, 1956, 1957) as *M. curema* (Cuvier and Valenciennes); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Pullen (1962); Stevens (1963b).

Family Atherinidae—Silversides

Membras martinica (Valenciennes)—Rough silverside*

Common along shore lines, usually in high salinity waters. Reid (1955a, 1955b, 1956, 1957) as *M. m. vagrans* (Goode and Bean); Renfro (1959a); Arnold, Wheeler and Baxter (1960) as *M. vagrans vagrans* (Goode and Bean); Pullen (1960, 1962); Stevens (1963b).

Menidia beryllina (Cope)—Tidewater silversides*

Common all year throughout the bay system. Fowler (1945); Reid (1955b, 1956, 1957) as *M. b. peninsulae* (Goode and Bean); Chambers and Sparks (1959); Renfro (1959a); Arnold, Wheeler and Baxter (1960) as *M. b. pensacolae* (Goode and Bean); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962); Stevens (1963b).

Family Polynemidae—Threadfins

Polydactylus octonemus (Girard)—Atlantic threadfin*

Common during the warmer months in high salinity waters. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Chambers and Sparks (1959); Hoese (1959b); Renfro (1959a); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

ORDER PLEURONECTIFORMES (HETEROSOMATA)

Family Bothidae—Lefteye flounders

Ancylopsetta quadrocellata Gill—Ocellated flounder *

Uncommon, found occasionally in the Houston Ship Channel. Fowler (1945); Hoese (1959b); Pullen (1960, 1962).

Citharichthys spilopterus Günther—Bay whiff*

Common during all seasons throughout the bay system, but most abundant in waters of moderate to high salinity. Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Hoese (1959b, 1959c); Renfro (1959a); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

Etropus crossotus Jordan and Gilbert—Fringer flounder*

Common during all seasons in moderate to high salinity waters. Fowler (1945) as *E. crossotus* Gilbert; Hoese (1959b).

Paralichthys albigutta Jordan and Gilbert—Gulf flounder *

Uncommon in this bay system.

P. lethostigma Jordan and Gilbert—Southern flounder*

Abundant all year throughout the bay system, but present in greatest numbers in moderate to high salinity waters. Chandler (1935); Fowler (1945); Reid (1955a, 1955b, 1956, 1957); Hoese (1959a); Renfro (1959a, 1959b); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962); Stevens (1963a, 1963b).

P. squamilentus Jordan and Gilbert—Broad flounder

Rare. Baughman (1950a).

Family Soleidae—Soles

Archirus lineatus (Linnaeus)—Lined sole*

Common throughout the year in moderate to high salinity waters. Fowler (1945) as *A. achirus* (Linnaeus); Reid (1955b, 1956, 1957); Renfro (1959a); Chin (1961); Pullen (1960, 1962).

Trinectes maculatus (Bloch and Schneider)—Hogchoker*

Common throughout the year in moderate to high salinity waters. Fowler (1945) as *Archirus fasciatus* Lacépède; Chambers and Sparks (1959) as *T. maculator* (Bloch); Hoese (1959b); Renfro (1959a, 1959b); Shidler (1960); Chin (1961); Pullen (1960, 1962).

Family Cynoglossidae—Tonguefishes

Symphurus plagiusa (Linnaeus)—Blackcheek tonguefish*

Common throughout the year in moderate to high salinity waters. This species is very abundant in the deep waters of the Houston Ship Channel. Fowler (1945); Reid (1955b, 1956); Hoese (1959b); Renfro (1959a); Chin (1961); Pullen (1960, 1961, 1962).

ORDER ENCHENEIFORMES (DISCOCEPHALI)

Family Encheneidae—Remoras

Echeneis naucrates Linnaeus—Sharksucker

Uncommon, found occasionally attached to rays and sharks. Pullen (1960, 1962).

ORDER GOBIESOCIFORMES (XENOPTERYGII)

Family Gobiesocidae—Clingfishes

Gobiesox strumosus Cope—Skilletfish*

Common in waters of high salinity. Hoese (1959a); Arnold, Wheeler and Baxter (1960); Shidler (1960); Chin (1961); Pullen (1960, 1962).

ORDER TETRAODONTIFORMES (PLECTOGNATHI)

Family Monacanthidae—Filefishes

Stephanolepis hispidus (Linnaeus)—Planehead filefish* (*see* Berry and Vogele, 1961)

Common in high salinity waters. Reid (1955b, 1956) as *Monacanthus hispidus* (Linnaeus); Shidler (1960) as *Monacanthus hispidus*.

Family Tetraodontidae—Puffers

Lagocephalus laevigatus (Linnaeus)—Smooth puffer*

Rare, collected in 1963 from East Bay by personnel of the Texas Parks and Wildlife Department and from West Bay by a local fisherman (personal communications).

Sphaeroides nephelus (Goode and Bean)—Southern puffer*

Common during summer and fall in high salinity waters. Reid (1955a, 1955b, 1956, 1957); Hoese (1959b); Renfro (1959a); Shidler (1960); Chin (1961); Pullen (1960, 1961, 1962).

S. testudineus (Linnaeus)—Checkered puffer

Rare. Baughman (1950b)

Family Diodontidae—Porcupinefishes

Chilomycterus schoepfi (Walbaum)—Striped burrfish*

Common during the warmer months in high salinity waters. Reid (1956, 1957); Renfro (1959a); Shidler (1960).

Diodon hystrix Linnaeus—Porcupinefish.

Rare. Baughman (1950b).

ORDER BATRACHOIDIFORMES (HAPLODOCI).

Family Batrachoididae—Toadfishes

Opsanus beta (Goode and Bean)—Gulf toadfish*

Uncommon, found in high salinity waters. Hoese (1959a, 1959b); Renfro 1959a, 1959b); Arnold, Wheeler and Baxter (1960); Chin (1961); Pullen (1960, 1962).

Porichthys porosissimus (Cuvier)—Atlantic midshipman*

Common during all seasons in moderate to high salinity waters, but most abundant in the ship channel and around oyster reefs. Fowler (1945) as *Nautopaedium porosissimum* (Valenciennes); Hoese (1959b); Renfro (1959a); Shidler (1960); Pullen (1960, 1962).

ORDER LOPHIIFORMES (PEDICULATI)

Family Antennariidae—Frogfishes

Histrio histrio (Linnaeus)—Sargassumfish

Although not a permanent inhabitant, this fish may be found upon occasion swimming near sargassum weed which has drifted in from the Gulf. Renfro (1959a).

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The Cytochrome Electrode System and the Bioelectric Field of the Cell

PART I: The E.M.F. in the root of *Allium cepa*.

PART II: The E.M.F. in the frog skin.

E. J. LUND, J. N. PRATLEY, AND HILDA F. ROSENE

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Abstract

Part I: The bioelectric potential and electric field of the root apex of *Allium cepa* is generated by the cytochrome system. It appears that this system must be oriented and must function as an electrode system. The axial distribution of cytochrome oxidase concentration corresponds to the distribution of electric potential and amplitude of change in potential in the root. The light reversible effect of CO on the cytochrome oxidase corresponds to its light reversible effect on the bioelectric potential and its distribution. The effects on the root apex correspond to those on the epidermis of the frog skin. Both are polar germinal systems.

Part II: The E.M.F. and electrical energy generated by the epithelial layer of the frog skin is derived from the oriented cytochrome system acting as an electrode system, as shown by the light reversible effect of CO on the E.M.F. This oriented energy output may be available for active transport. The distribution of concentration of cytochrome oxidase in the epidermis, as shown by the Nadi test, corresponds to the polar structure and maintained potential across the skin. It is shown that unequal distribution of potential in different areas of the skin presents difficulty for interpretation of results from application of so-called "short-circuit" procedures.

PART I: The E.M.F. in the root of *Allium cepa*.

Introduction

There are at present two major unsolved problems which confront the electrophysiologist and those concerned with transport. They may be stated as follows: (1) What is the electrochemical mechanism by which chemical potential energy is transformed, in the establishment of bioelectric potentials and in the oriented flow of electrical energy in polar cells, tissues, and organs? (2) What is the source of energy required for active transport in these polar systems?

These phenomena require consideration of both the intensity factor (potential difference) and the capacity factor (electric current). Very often concern has been limited to one of these to the exclusion of the other. Historically, segregation of the facts bearing on each one of these aspects led to and became associated with the two present theories of the origin of bioelectric potentials: (a) that these differences of potential were due mainly to differences in concentration of inorganic ions, a theory which originated years ago with Nernst and Bernstein, and (b) that the E.M.F.'s were the result of oriented oxidation reduction potentials of catenary systems in the state of flux in the polar structure of the cell.

The Nernst-Bernstein theory could not in general account for those phenomena in which a maintained source of energy was required, *e.g.*, active transport, hence the

concept of the "pump" (ion) as a source of energy was later invented by others without experimentally identifying its mechanism.

Consideration of many of the limitations of the theory of Nernst and its later development, originally led Lund (1928a) to formulate in detail an explanation of continuously maintained bioelectric "currents" and associated electrical potentials. This formulation was based on the assumption that these are oxidation-reduction equilibria in the state of flux (open systems) in the cell. Stable or "resting" potentials, where observed output of electric current was constant, were explained as due to a maintained "flux equilibrium" state of the catenary reactions in the oxidation-reduction system of the cell.

This formulation at no time excluded the obvious fact that differences in ion concentration often are definitely responsible for certain potential differences in cells and tissues (Lund and Stapp, 1947). Both concepts must be recognized because it is often easy to show that both kinds of origins of potential occur superimposed upon one another (cf. below).

The concept of the "pump" involves two main aspects: (a) identification of the electrochemical mechanism which supplies the energy for active transport and (b) the protoplasmic fine structure—"membrane"—in and by which the energy is transformed and oriented in performance of the useful work of transport. The vector properties of transport are apparently conferred by the observed oriented fine structure of the macromolecular "machine"[1] (Mitchell, 1961). Insofar as the authors are aware, no specific source has yet been demonstrated which provides the energy required for the maintained bioelectric field of the polar cell or the energy required for active ion transport.

The following experiments showing the specific effect of carbon monoxide and light applied in combination and separately, have afforded a method for the identification of the cytochrome system as the source of the energy for production of this electromotive force (E.M.F.) in the root tip, an electrically polar meristematic tissue, and in all probability, also a source of energy for active ion transport. Furthermore, identification and distribution of concentration along the root of this cytochrome system by means of the Nadi reagent reinforces the experimental findings in regard to the origin of the E.M.F. by the use of carbon monoxide and light.

For present purposes it does not appear necessary to review the very extensive work on the identification and properties of this complex and the effects of carbon monoxide on metabolic processes. For the present study the basic fact established by all this work is the specificity and uniqueness of the light reversible effect on the carbon monoxide-cytochrome oxidase complex.

Procedure

Electrical potential measurements were made on the young roots of *Allium cepa* which were grown in full strength aerated Hoagland's solution in the dark. When the roots had attained a length of between 30 and 40 mm, all but one were excised, and the bulb with its remaining root was quickly placed in the experimental chamber (Fig. 1), where it was allowed to equilibrate for a period of at least one hour before potential measurements were begun.

[1] "Machine" as used here is any material system which determines the vector properties of flow of energy which is transformed and/or transferred through the system.

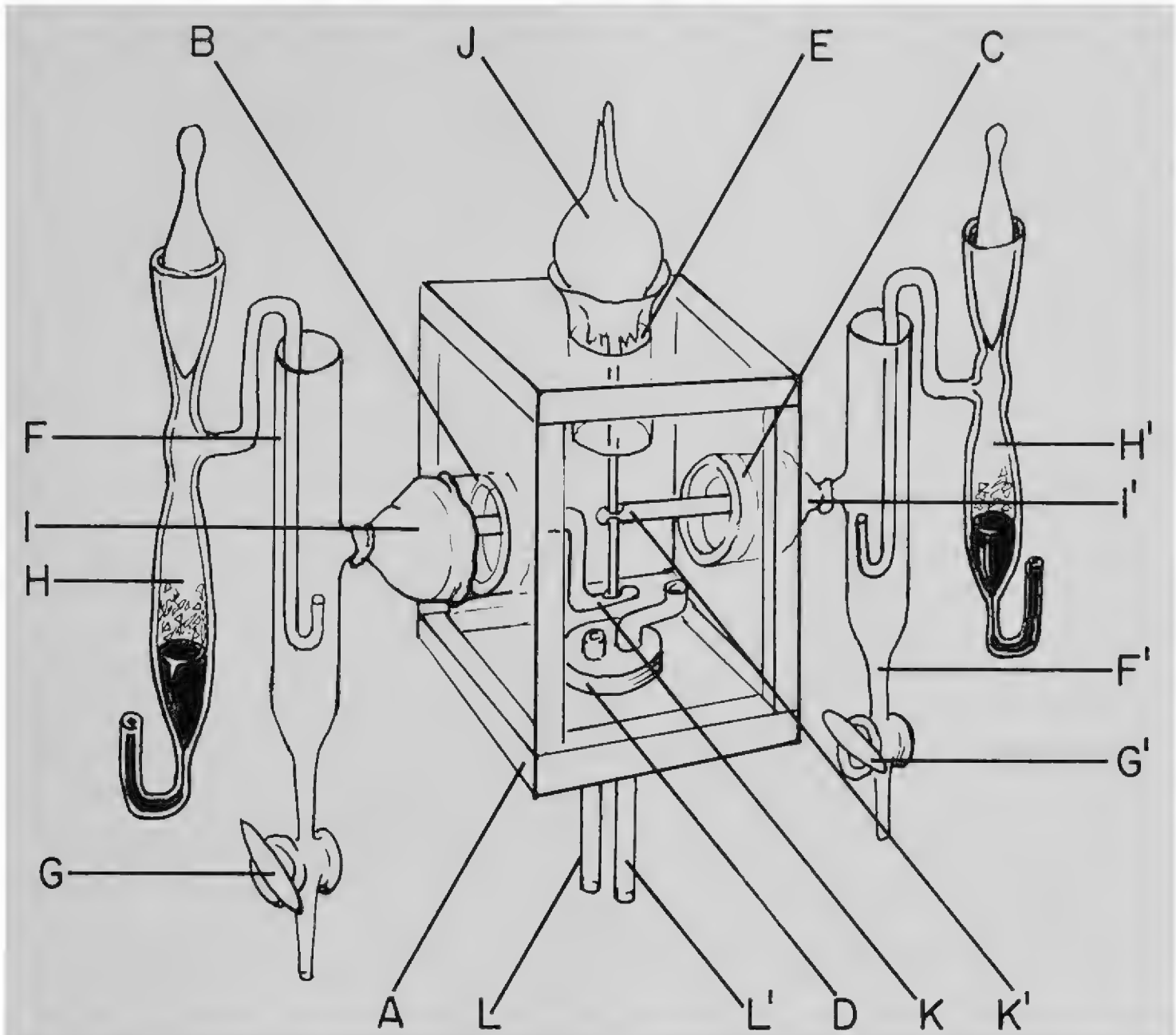

FIG. 1. Experimental Chamber (Description in Text).

Since it appeared desirable to alter quickly the composition of the gases in the experimental chamber in order to follow closely changes in the electrical pattern exhibited by the root without disturbing the onion root-Hoagland solution interphase at the contacts, the smallest possible chamber was constructed. The essential details of this chamber are shown in Fig. 1. The airtight chamber proper, A, was constructed of Lucite with internal dimensions of $3.5 \times 2.0 \times 2.0$ cm. Four holes were drilled for inserting three plastic sleeves, B, C, and D, and one glass collar, E. Through sleeves C and B were inserted the arms of contact cups F and F′ which were fitted with stopcocks, G and G′, for washing the saturated zinc sulphate-zinc amalgam electrodes, H and H′. Finger cots I and I′ permitted an airtight seal for the holes and maneuverability of the contact cups by means of three dimensional rack and pinion type micromanipulators (not shown) to which the cups were clamped. The onion bulb, J, was seated on the glass collar and was held in an airtight position by modeling clay. The outside surface of the collar was coated with a sealing lubricant. A glass rod, not shown, was fused to the collar and clamped to a micromanipulator.

Thus, by means of three micromanipulators and a horizontal microscope the onion root could be threaded into the glass ring contacts, K and K′, which were attached to the ends of the contact cup arms, with minimum disturbance of the root. The contact cups

were filled with full-strength Hoagland solution, thereby permitting electrical contact with the same kind of solution in which the root was grown. Sleeve D was fitted with a two hole rubber stopper through which gases were passed by inlet and outlet tubes, L and L′. All gas mixtures were first passed through gas washing towers to saturate the gases with water vapor. As a further precaution to the maintenance of a humidified atmosphere within the chamber, wet cotton and moistened filter paper lined the bottom and two sides of the chamber.

Copper wire leads from the isoelectric electrodes were connected to a two-way shielded switch. Electrical measurements were made with a duBridge amplifier and Rubicon galvanometer whose sensitivity was controlled by a matching Ayrton shunt. The amplifier and the galvanometer were calibrated and checked against a Standard Cell. Within the range of galvanometer deflections observed in the experiments, the response of the galvanometer was essentially linear. The shunt was adjusted so that a 1 mm deflection of the galvanometer was equivalent to approximately 1.5 mv. The entire apparatus was adequately shielded and grounded.

Illumination was provided by a 100 watt incandescent projection bulb. The light was passed through two water filters and a microscope iris diaphragm. The intensity of the light on the root was approximately 400 foot-candles. Under experimental conditions, there was no change of temperature in the chamber during illumination by light. The light source could be adjusted by means of a rack and pinion for illumination of the entire root or illumination of 2 mm at either the apical (apical spot illumination) or basal contact (basal spot illumination). During any one of the experiments the temperature in the chamber did not vary more than ± 0.2 C.

After the root had equilibrated in the chamber for one hour, it was threaded into the ring contacts, and a "map" was made of the potential gradient along the longitudinal axis of the distal 10 mm. The apical contact was placed at the tip of the root so that the root touched the top meniscus in the ring contact but did not extend through the contact; the basal contact was located 10 mm from the tip, as measured from the lower meniscus of the basal contact to the upper meniscus of the apical contact. "Mapping" was carefully performed with the aid of a horizontal microscope to avoid any mechanical disturbance of the root by moving the apical contact upward at 2 mm increments until it touched the basal contact and electrical shorting occurred.

This mapping procedure was performed immediately before the beginning of each experiment. In addition, as will be shown later, mapping was carried out on some roots every fifteen minutes for one hour—the duration of most experiments in this series —to determine the stability of the potential gradient.

In all experiments in which the effects of carbon monoxide were to be tested, an 80 per cent carbon monoxide and 20 per cent oxygen mixture was used. Inhibition of cytochrome oxidase by carbon monoxide is due to the fact that it is competitive with oxygen for the enzyme and in most physiological studies it appears that high carbon monoxide/oxygen ratios are required. Under such conditions, the added problem of separating the anaerobic effect of lack of oxygen from the carbon monoxide effect is encountered. Fortunately, in this study, an 80/20 ratio was found adequate to inhibit, and thus, any anaerobic effect from lack of oxygen could be ruled out.

Gas mixtures of 80 per cent carbon monoxide and 20 per cent oxygen were prepared in the usual manner and humidified. It was found that 300 cc of gas mixture could be

sent through the chamber in one minute which was assumed to be more than sufficient to replace the approximate 14 cc volume of air in the chamber.

All experiments, with the exception of preliminary ones in which maps of potential gradients were made, were divided into three periods: (1) an initial period during which potential measurements were made every minute when the root was in a humidified air environment and in the dark, (2) a test period [s] during which either gases were introduced, light was projected on the root, or both, and (3) a recovery period when conditions in the chamber were the same as those in the initial period. Experiments were performed for various lengths of time for the different periods; *e.g.*, when the root was subjected to carbon monoxide for only five minutes before light was applied and in other experiments when the root was subjected to carbon monoxide for thirty minutes. Various combinations were tried, the results of which were similar. Data from those experiments in which the time periods were of 15 minutes duration are presented.

During the three experimental periods, the distance between the apical and basal electrode contacts on the root was 6–8 mm compared to 10 mm during the mapping procedure. The reason for moving the basal contact nearer the root tip was to obtain a unidirectional gradient as shown in Fig. 2. This interelectrode region of 6 to 8 mm is here designated as the "root apex" (Rosene and Lund, 1935). It is a region in which active cell division occurs in the distal 2 mm, as compared to relatively mature differentiated tissue in the proximal 2 mm.

The Potential Gradient in the Root-Apex

The experiments of Lund and Kenyon (1927) were the first attempts to measure accurately the magnitude, direction, and distribution of continuously maintained electric potentials in the unstimulated onion root. It was reported then, and later substantiated by other workers, that the inherent electrical potential is characteristically a fluctuating quantity whose value is dependent upon spatial and temporal factors. Electrical potential gradients along the apical fifteen millimeters of the longitudinal axis of young attached unbranched onion roots, when plotted graphically, frequently exhibit curves with multiple fluctuations which are peculiar to each root. The apical region of active cell division is electropositive, in the external circuit, to all proximal regions. The temporal fluctuations of the electrical potential of the root are manifested as difference of the potential between any two loci on the root and also as fluctuations of the potential gradient between the same two loci. Lund and Berry (1947) have made a detailed study of the spontaneous variation in the potentials of the root and have shown that the greatest amplitude of variability is in the apical five millimeters.

It was first suggested by Lund and Kenyon (1927) and later experimentally demonstrated by Marsh (1928), Rosene and Lund (1935), and Rosene (1935) that the principle of algebraic summation of individual cell electrical potentials holds for the onion root; *i.e.*, each cell which has electrical polarity contributes a part of the total electrical pattern of a polar tissue or organ. The proof for algebraic summation in the onion root is the fact that the application of respiratory inhibitors, localized removal of oxygen, and short-circuiting regions between but not at the electrode contacts produces characteristic predictable alterations of the potential between the electrode contacts. The type (increase or decrease) and magnitude of change is dependent upon

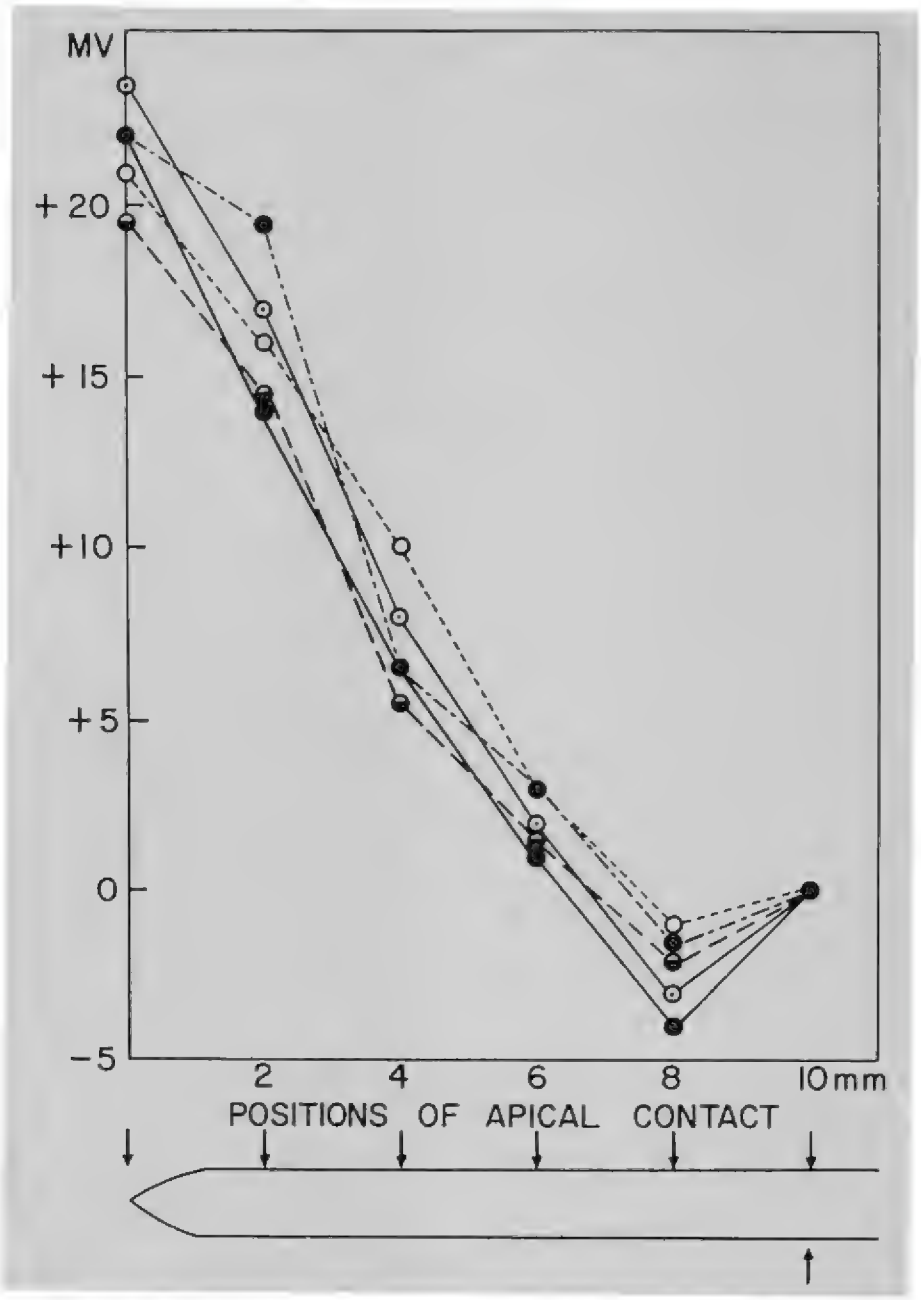

FIG. 2. Maps of potential gradients determined on a single intact onion root over a period of one hour. Each curve, representing a map of the potential gradient, was obtained by separate mapping procedure taken every fifteen minutes. The experimental chamber was filled with moist air. The diagram of the root below the curves is drawn to scale on the abscissa. Arrows at the top of the diagram of the root indicate consecutive positions of the positive electrode contact beginning at the tip, while the arrow at the bottom indicates the position of the stationary negative electrode contact.

where in the inter-contact region the agent is applied, oxygen is removed, or a short-circuit is introduced. For example, Rosene (1935) demonstrated that when a column of tap water, acting as a liquid shunt, was applied to a local region (the component cells of which manifest a "component polarity" positively oriented within the inter-contact region) a diminution of the potential between the electrical contacts occurred. But, on the other hand, when the "short-circuit" was applied to another region with a component polarity oppositely oriented, an increase in the total potential occurred. That is, when local gradients between the electrical contacts were oppositely oriented, opposite effects of the shunt on such gradients were noted. Similarly, opposite effects on the electrical polarity of the onion root were noted when potassium cyanide or hydrogen was applied locally to oppositely oriented component potentials of the region between the electrode contacts.

It is evident, therefore, that whenever the effects of external agents are to be tested on the electrical potential of the onion root, the distribution of the potentials along the root axis must be carefully taken into account. Two avenues of experimental approach

to study the effect of carbon monoxide on the potential may be followed: (1) Carbon monoxide could be applied locally by means of a jacket; (2) Carbon monoxide could be applied to the whole root. In either approach the distribution curve of component potentials along the axis must be plotted in order to obtain uniform and interpretable results of the effects of carbon monoxide on the potential measured between the contacts. The second alternative was the more practical, and furthermore would permit the results of experiments of reversal of carbon monoxide effects with illumination of the whole roots or parts of the root to be readily interpretable in respect to the potential gradient.

Regions exhibiting a single unidirectional potential gradient are desirable in experiments. Otherwise, if measurements were made in a region of the root having opposing gradients between the electrode contacts, changes in the magnitude of the component potential in opposing gradients due to carbon monoxide would algebraically summate, and hence the full effect, if any, might be obscured. Furthermore, if the opposing potential gradients were equal and opposite, an effect of carbon monoxide would not be discernible. There are other advantages in working with a single unidirectional potential gradient which will become obvious later.

It was pointed out above that gradients of electrical potentials in unstimulated roots are spontaneouly variable within small limits with respect to time, space, and individual roots. The occurrence, however, of a unidirectional potential gradient in roots of the present study appears to be the rule, within the region of the root-apex. Numerous maps of potential gradients of different roots verified this observation. Fig. 2 represents typical curves of the potential gradient determined on a single root every fifteen minutes for one hour. The time required to make a complete map was five minutes. Since the potentials are fluctuating quantities, instantaneous determinations of the potential gradient would be desirable, but technical difficulties precluded this. The contacts could not be moved faster without the risk of mechanical stimulation of the root and multiple contacts would involve complex circuits in the experimental apparatus. It is important to note in Fig. 2 that the overall shape of all the curves is similar over the one hour period, although individual maps were made fifteen minutes apart and the magnitude of the component potentials differs from one fifteen minute period to the next. It may be concluded, therefore, that if contacts were placed at the tip and 8 mm proximal to the tip, the potential gradient would remain unidirectional for a period of one hour. The possibility exists, however, that opposing gradients of smaller magnitude represented by small peaks or valleys between the plotted points may exist; although not detectable by the present mapping technique. Such small opposing gradients, if present, did not show in the summation pattern as mapped.

The Photoreversible Effect of Carbon Monoxide Inhibition of the Root Apex Potential

Fig. 3 represents typical control experiments on two roots to test the effect of light on the potential and on temperature in the chamber when the contacts were placed at the tip and 7 mm from the tip. Curve A shows that the potential is not affected when light is projected on the entire length of the root between the contacts nor is the temperature appreciably affected as shown by Curve A′. Curves B and B′ which are similar to curves A and A′ were obtained when the distal 2 millimeters only were illuminated. Curves A

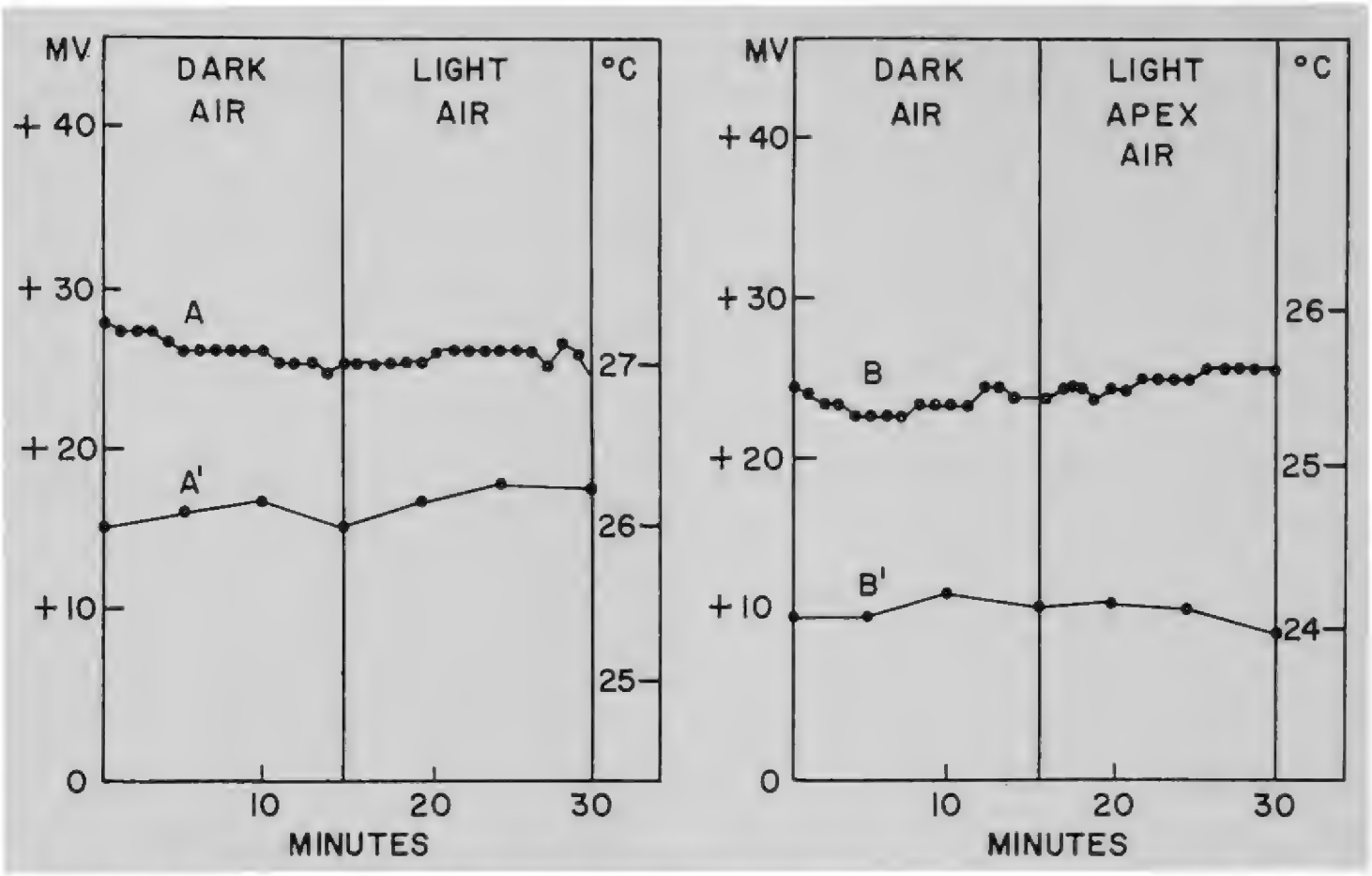

FIG. 3. Effect of light on the potential of an intact onion root and on the temperature in the experimental chamber. Curves A and B have millivolts as their ordinates. Curves A′ and B′ have temperature in the experimental chamber as ordinates. The experimental chamber was filled with moist air.

and B also indicate the degree of fluctuation of the potentials of different roots—in this instance represented by the almost complete absence of fluctuations. Roots exhibiting such steady potentials were not uncommon and have been reported previously in the literature (Marsh, 1928).

When a root is exposed to 80 per cent carbon monoxide and 20 per cent oxygen, there is a precipitous drop in the potential between contacts as illustrated in Fig. 4. The inset curve of this figure represents a map of the potential gradient of the 10 mm region before the experiment was started. During the experiment, contacts were 6 mm apart with the apical contact at the tip, hence, there was a unidirectional potential gradient between the contacts. During the exposure of the root to the mixture of carbon monoxide and oxygen (CO-dark period), there was an immediate reversal of the orientation of the potential—*i.e.*, the apical region became strongly electronegative to the basal intercontact region which represents an inverted electrical polarity, opposite to the normal condition. Throughout the CO-dark period, the potential remained depressed, although in this root the potential increased. When light was projected on the entire length between the contacts while the root was still exposed to the carbon monoxide-oxygen mixture ("CO-light period"), there was an immediate increase in the potential, showing that light reversed the inhibitory effect of carbon monoxide, thus returning the slope of electrical gradient to its original state. In fact, the potential in the CO-light period showed a rebound phenomenon—*i.e.*, the potential was significantly higher (steeper gradient) than in the initial period in the absence of carbon monoxide. Subsequently, the potential declined to initial period values, and finally when air was readmitted to the chamber in the recovery period, it continued its decline, rose again, and reached a level below the initial period values.

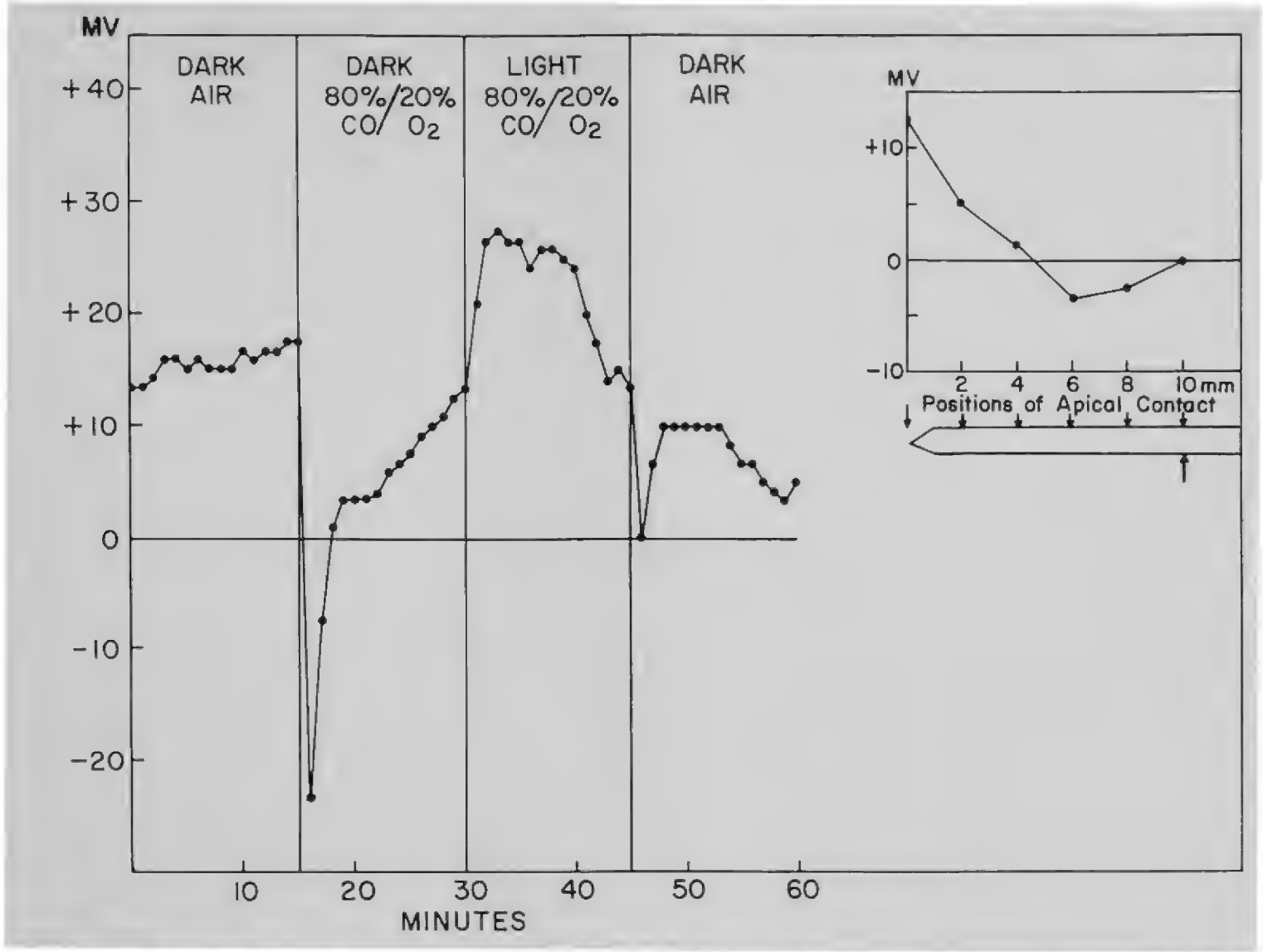

FIG. 4. Typical time course curve showing the effect of carbon monoxide on the potential of an onion root and its reversal by light applied to the entire region between the electrode contacts. Inset curve shows the map of the potential gradient of this particular root. The positive electrode contact was placed at the tip of the root, and the negative electrode was placed six millimeters from the tip.

Fig. 5 shows the results of another experiment performed in exactly the same manner as above. The curves in Figs. 4 and 5 show typical results obtained in all experiments of this type. They also illustrate that variations occur in the electrical behavior of roots under similar experimental conditions. Fig. 5 shows more initial fluctuation in the potential, which, during the CO-dark period, remained depressed and reversed in polarity. This pattern of the potential in the CO-dark period is common in such experiments.

The salient features of these experiments are that carbon monoxide decreases the polarity potential of the root-apex and light completely reverses this decrease, thus demonstrating the participation of cytochrome oxidase in the origin of the potential.

Since the carbon monoxide-oxygen mixture was applied uniformly along the length of the root, the depression of the potential between the contacts represents an unequal effect of equal concentrations of carbon monoxide on the cytochrome oxidase system in different regions between the contacts. The depression of the normal electrical polarity of the root-apex denotes that distal component cell potentials were affected more by carbon monoxide than were proximal component cell potentials of the root-apex (Lund, 1931).

If, therefore, maps of the potential gradient along the root between contacts were made during exposure to the carbon monoxide-oxygen mixture, it would be expected that the magnitude of the component potentials in the proximal region would be decreased less than the component potential in the distal region, resulting in an over-all

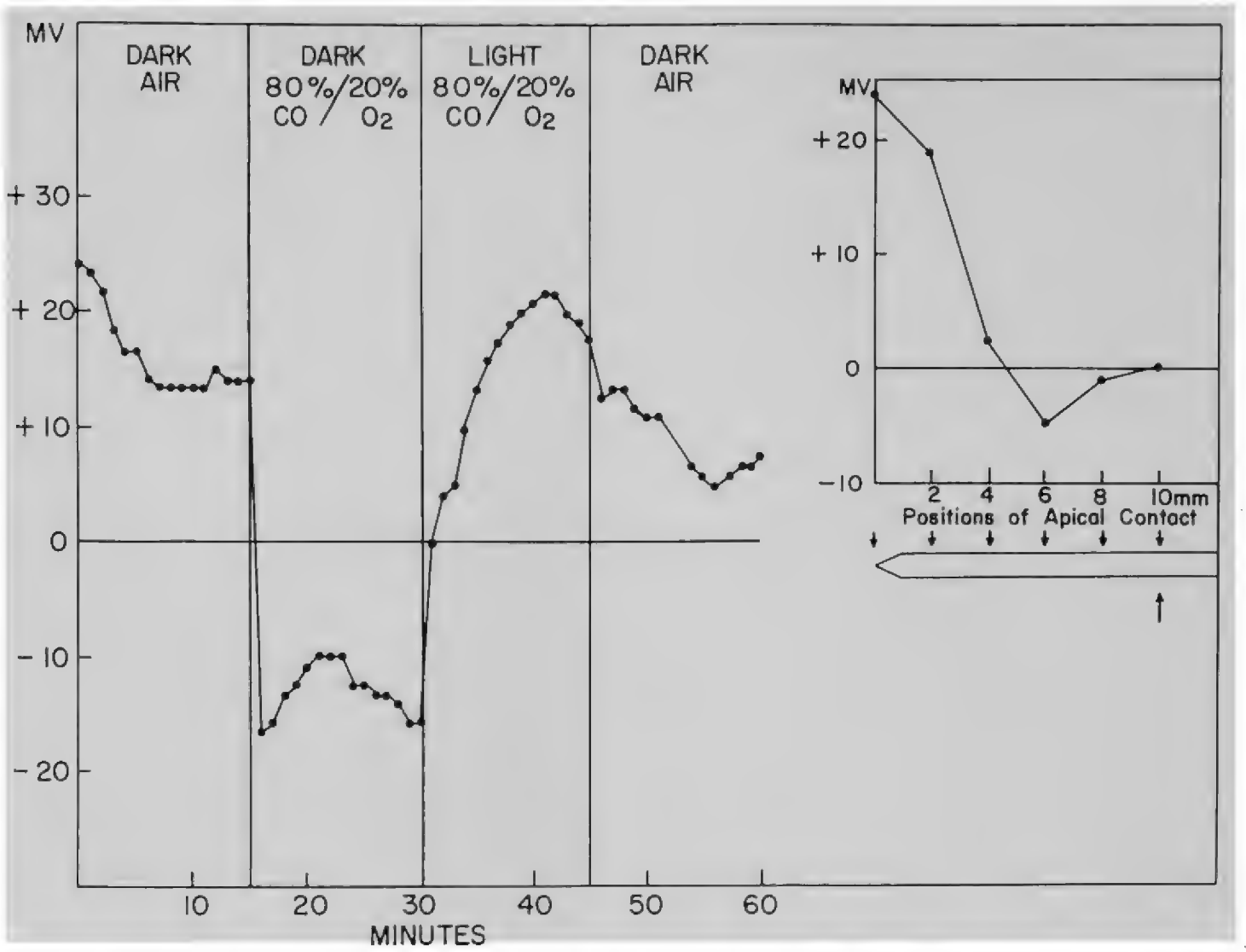

FIG. 5. Typical time course curve showing the effect of carbon monoxide on the potential of an onion root and its reversal by light applied to the entire region between the electrode contacts. Inset curve shows the map of the potential gradient of this particular root. The positive electrode contact was placed at the tip of the root, and the negative electrode was placed six millimeters from the tip.

reversal of the potential gradient in a direction opposite to that characteristic of the root in the initial period as has often been shown previously to occur when, for example, the onion root-apex is exposed to hydrogen (Rosene and Lund, 1935).

The unequal effects of equal concentrations of carbon monoxide on different regions of the root may be demonstrated, however, in another manner. Since it was established above that light completely reversed the carbon monoxide inhibition, localized applications of light to different regions between the contacts when the root is exposed to carbon monoxide should result in different effects on the potential.

Effects of carbon monoxide and carbon monoxide-light reversal on the potential when illumination was restricted to the apical 2 mm of the root-apex are presented in Figs. 6 and 7. The pattern of carbon monoxide inhibition of the potential and light reversal of this effect is similar to that in Figs. 4 and 5, but illumination of 2 mm at the root tip (CO-light-apical period) resulted in a larger rebound in the potential. At the highest point (rebound of the potential) of the curve in the CO-light-apical period, the magnitude of the potential was much higher than that of the initial period. The results shown in Fig. 7 essentially duplicate those in Fig. 6; the magnitude of carbon monoxide depression was greater, but the rebound in the CO-light-apical period was not as pronounced. Generally, from the results of experiments not shown, greater rebound of the potential was evident when carbon monoxide-inhibited roots were illuminated at the

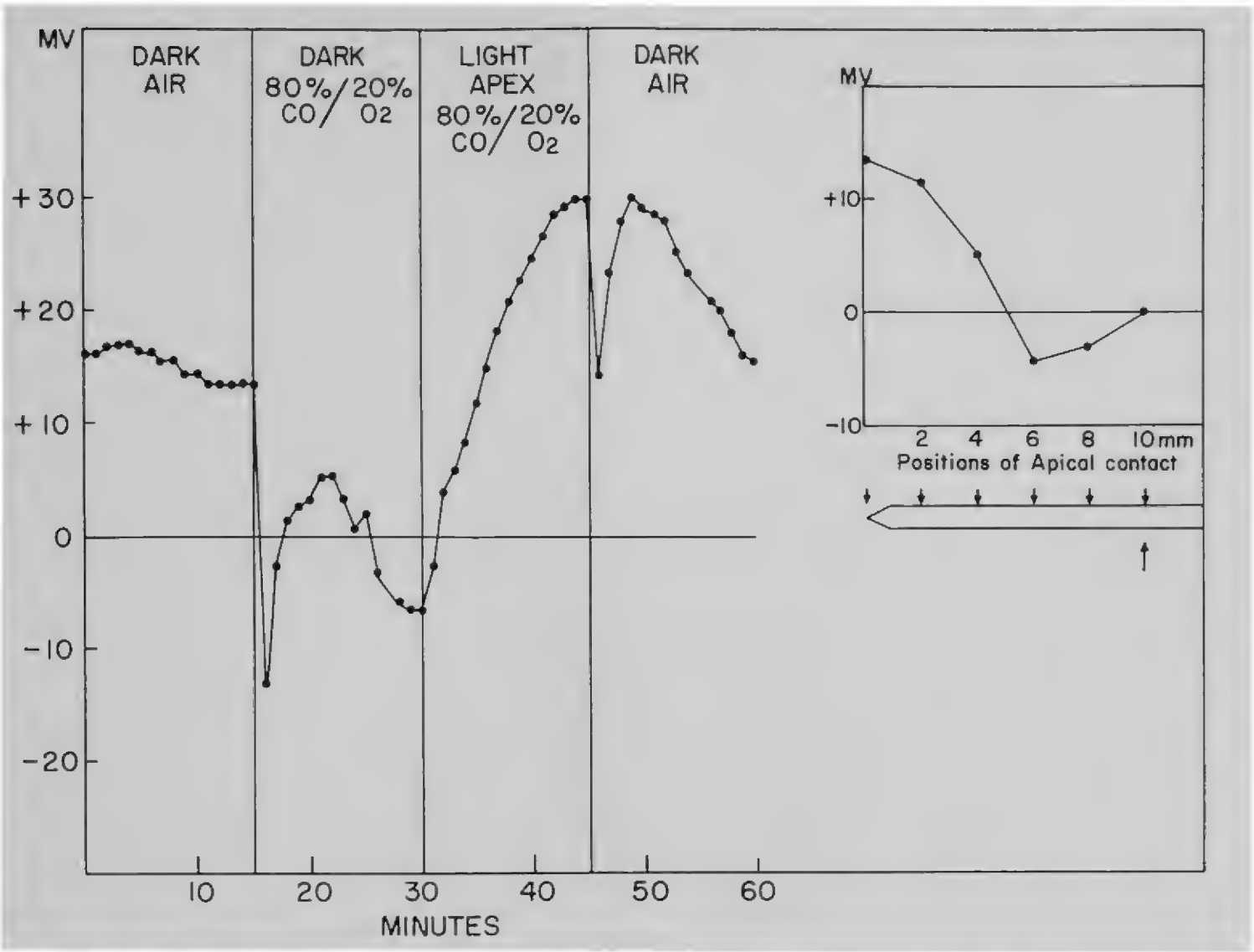

FIG. 6. Typical time course curve showing the effect of carbon monoxide on the potential of an onion root and its reversal by light applied to the distal 2 millimeters (light apex) of the root. Inset graph shows the map of the potential gradient of this particular root. The positive electrode contact was placed at the tip of the root, and the negative electrode was placed six millimeters from the tip.

apical 2 mm as compared to illumination of the entire region between the electrode contacts. This is very probably due to or associated with a greater concentration of cytochrome oxidase in the apical 2–3 mm of the apex.

Effects of carbon monoxide and carbon monoxide-light reversal on the potential when illumination was restricted to the proximal (basal) 2 mm of the inter-contact region are illustrated in Figs. 8 and 9. The pattern of carbon monoxide inhibition of the potential during the dark period in these experiments is similar to those in Figs. 4–7. But in the curves of Figs. 8 and 9 it may be noted that illumination in the "CO-light-basal period" did not initially result in reversal of the carbon monoxide inhibition of the potential. In fact, the potential initially dropped to a lower level than in the CO-dark period as was to be expected, due probably to lower concentration of cytochrome oxidase in the proximal region.

The striking dissimilarities of the CO-light periods of the curves in Figs. 6 and 7 as compared to those in Figs. 8 and 9 prove that different regions of the root-apex are affected unequally by the same intensity of light. Furthermore, these dissimilarities cannot be due to other factors since conditions in all experiments were the same except for the loci of illumination. Therefore, since the changes of the carbon monoxide inhibited potential of roots with CO-apical illumination is greater and opposite to the changes with CO-basal illumination, the data indicate that the concentration of cytochrome oxi-

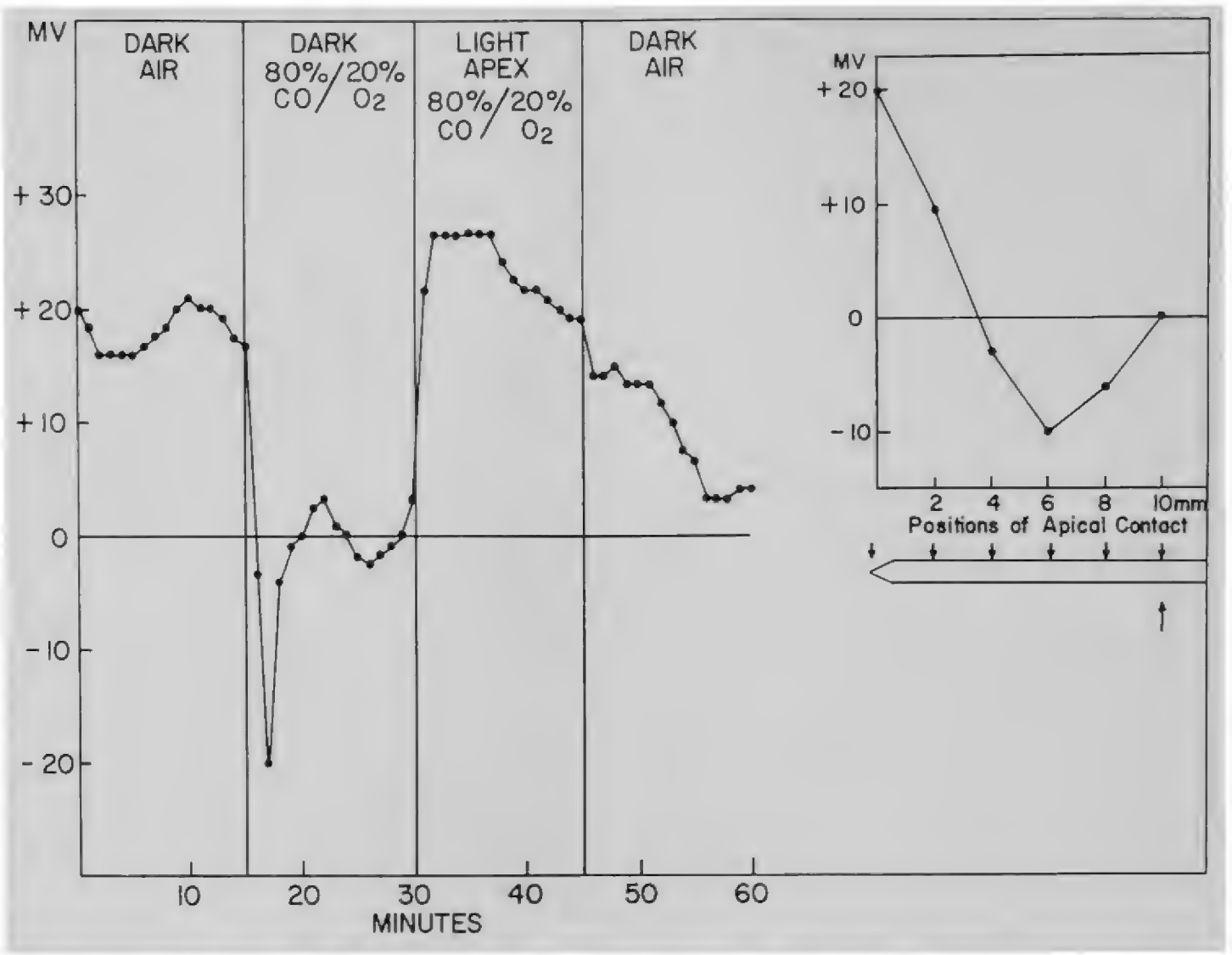

FIG. 7. Typical time course curve showing the effect of carbon monoxide on the potential of an onion root and its reversal by light applied to the distal 2 millimeters (light apex) of the root. Inset graph shows the map of the potential gradient of this particular root. The positive electrode contact was placed at the tip of the root, and the negative electrode was placed six millimeters from the tip.

dase in the root-apex is greater in the more apical region than in the basal region. The correctness of this conclusion is further shown by the following experiments using the "Nadi" reagent to determine the distribution of concentration of cytochrome oxidase in the root-apex.

CORRESPONDENCE BETWEEN THE GRADIENT OF ELECTRICAL POTENTIAL AND THE GRADIENT OF CONCENTRATION OF CYTOCHROME OXIDASE

The Nadi reagent was prepared according to Moog (1943). N, N-Dimethyl-p-phenyl-diamine(Eastman) was dissolved in water and prepared fresh for each test, but alpha napthol (Eastman) was dissolved in 10 per cent alcohol; roots exposed to this concentration of ethyl alcohol for 5 minutes showed no injury, and continued to grow normally. Distilled water or Hoagland solutions, both aerated or unaerated, were used in the experiments and tests were made to determine the rates of auto-oxidation of the Nadi reagent in these solutions. The blanks showed that the Nadi reagent in unaerated solution, as expected, had the slowest rate of auto-oxidation. A faint blue color would appear in the reagent after thirty minutes of exposure to air. Nadi reagent in aerated solvents at the end of the thirty-minute period was slightly bluer. No difference between Hoagland solution and distilled water as solvents was distinguishable, indicating that no elements in Hoagland solution catalyze the reaction. Solutions of 0.04 M sodium azide

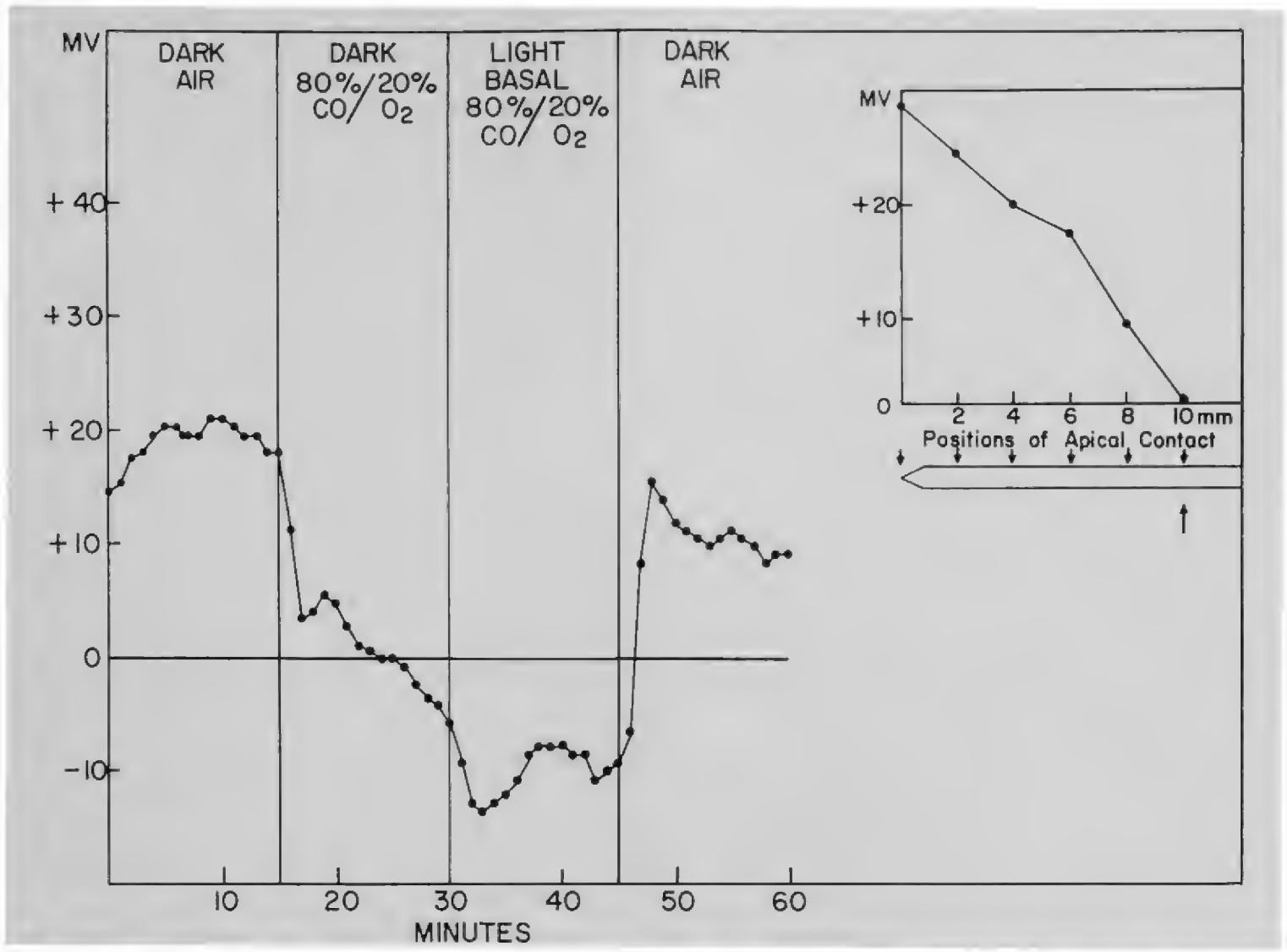

FIG. 8. Typical time course curve showing the effect of carbon monoxide on the potential of an onion root and its reversal by light applied to the proximal 2 millimeters (light basal) of the root. Inset graph shows the map of the potential gradient of this particular root. The positive electrode contact was placed at the tip of the root, and the negative electrode was placed six millimeters from the tip.

(Eastman) in the different solvents and in Nadi reagents were also prepared. Azide is considered to be a relatively specific inhibitor of cytochrome oxidase, and Rosene (1947) has found this concentration to inhibit effectively and reversibly water transport and oxygen consumption of the onion root. All solutions were adjusted to pH 5.0 since Lison (1936) has reported this value to be the optimum for plant tissue, and the tests were carried out at room temperature (24 C). All color observations were made with either a hand lens or a dissecting microscope of low magnification.

Both intact and excised roots were exposed to the Nadi reagent. In the experiments on intact roots, the onion bulb with one attached root was placed on a movable holder within an air tight chamber, similar to that illustrated in Fig. 1. By means of the holder, the root could be lowered into or raised from a cup to which the Nadi reagent could be added, or replaced by another solution. All manipulations were made from the outside. In those experiments during which the carbon monoxide-oxygen mixture was run into the chamber and the effect on the Nadi reagent was determined in the dark, light of low intensity was used for observing color changes; light from a fluorescent source was used for the photoreversible effect. In the experiments on excised roots, the severed roots were placed in a large dish containing their respective growth media (roots grown in distilled water or Hoagland solution) for a one hour adjustment period, and then transferred to watch glasses containing various test solutions.

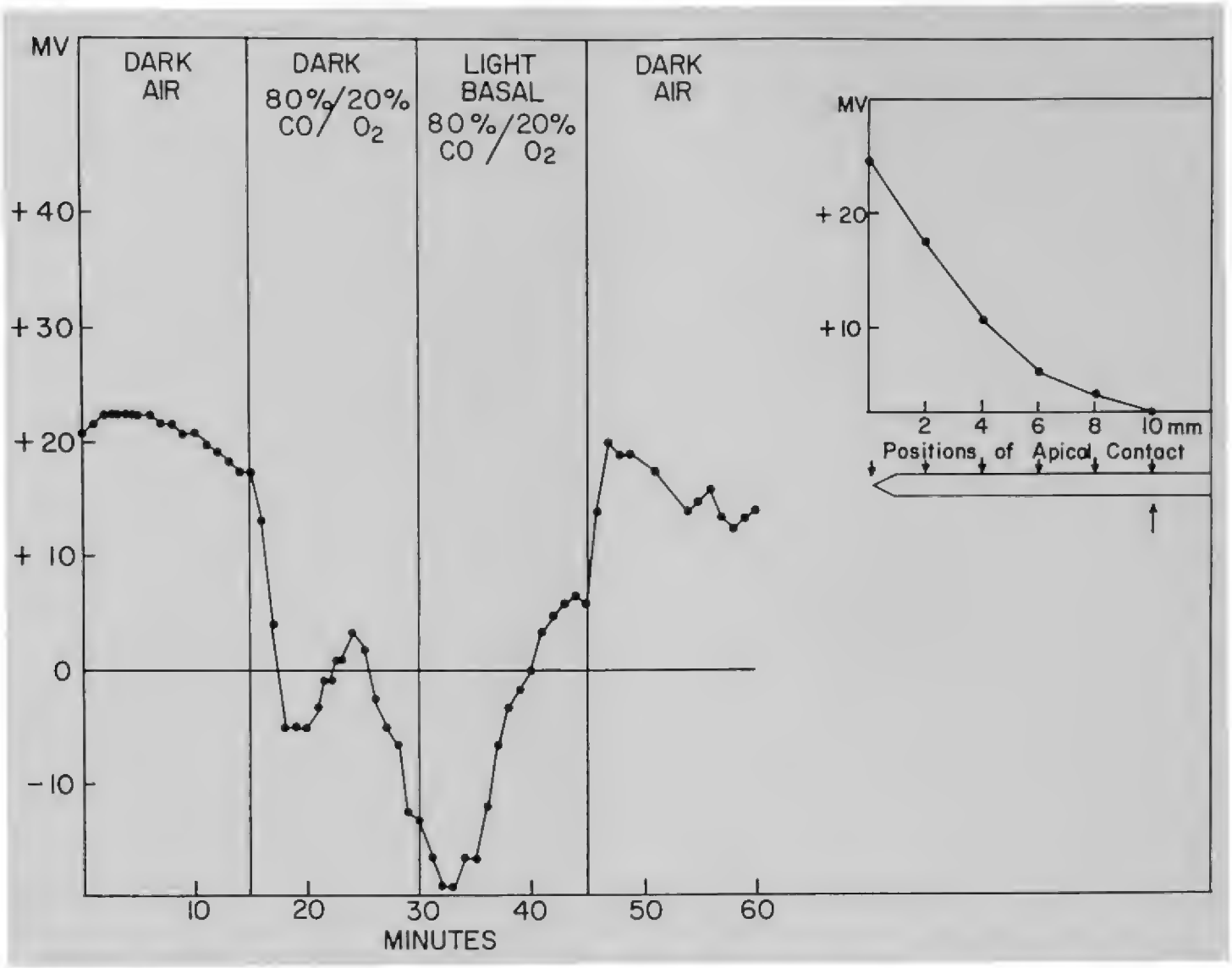

FIG. 9. Typical time course curve showing the effect of carbon monoxide on the potential of an onion root and its reversal by light applied to the proximal 2 millimeters of the root. Inset graph shows the map of the potential gradient of this particular root. The positive electrode contact was placed at the tip of the root, and the negative electrode contact was placed six millimeters from the tip.

When excised roots were placed in 15 per cent formalin, which destroys the activity of cytochrome oxidase, for 15 minutes before the Nadi reagent was applied, no color was developed in the root in a one-hour observation period; apparently, the M-Nadi reaction does not occur in the onion root.

All procedures, using aerated or unaerated Hoagland solution, aerated or unaerated distilled water, with roots grown in Hoagland or in distilled water, produced a distinctive pattern of color gradation along the root-apex in both intact and excised roots when exposed to the Nadi reagent. Varying the time of exposure to the reagent from five minutes to one hour showed that five minutes was ample time for the Nadi regaent to permeate since the distinctive distribution of color intensity was not altered by the prolonged exposure of one hour.

That the color gradations given by the Nadi reagent were due to differences in diffusion rates along the root-apex is contraindicated by the fact that different roots exposed for five minutes to oxidized Nadi show a uniform color development. Hence, the absorption of oxidized Nadi appeared to be uniform throughout the length of the root. It can be assumed, therefore, that a 5-minute period of exposure was of sufficient length to allow the Nadi reagent to permeate equally different regions of the root.

Exposure of intact roots to the mixture of 80 per cent carbon monoxide and 20 per cent oxygen in dim light gave a negative Nadi test. But, when the roots were illuminated, the distinctive gradation of color along the root axis appeared. These

results and those with excised roots exposed to azide affirm the specificity of the Nadi reagent. In the azide test, the roots were immersed for 5 minutes in 0.04M azide, 5 minutes in Nadi reagent containing 0.04M azide, and subsequently in 0.04M azide. In a one-hour observation period no color in any part of the roots could be observed.

The distinctive pattern of blue color gradation in the root-apex when exposed to the Nadi reagent for five minutes shows a deep blue color within the apical (distal) 1.5–2 mm region which is followed by a progressively fainter blue color to the 6–8 mm level, depending on the individual root. Varying degrees of color appeared in regions proximal to the 10 mm level in the roots which were 30 to 40 mm in length when tested, but the degree of color did not reach the characteristic deep blue color present in the root-apex.

This distinctive gradation of color reaction shows that there is a gradient in the concentration of cytochrome oxidase in the root-apex with the highest concentration within the distal 2 mm region. There is a close correspondence between the concentration of cytochrome oxidase and the magnitude of the potential per unit length of the apical 15 mm of the onion root-apex (Lund and Kenyon, 1927).

The various experiments with the Nadi reagent using carbon monoxide, azide, oxidized Nadi, and formalin confirm this conclusion, although they lack high quantitative precision of measurement of color intensity (Straus, 1954).

Discussion

It is interesting to recall that thirty-seven years ago when it was first proposed (Lund, 1928 a and b) that maintained bioelectric fields were caused by oxidation-reduction potentials of the respiratory process, the objection was made by some investigators that "first class electron conductors (metals) did not exist in cells and therefore the observed electrical phenomena could not be due to oxidation-reduction potentials." For an example of recent concepts see Cope (1963) and Jahn (1961). In this connection it may be stated that the distribution of potential (re-dox) on the onion root tip may be readily measured using a platinum wire loop with phosphate buffer in the liquid contact between the root surface and the platinum electrode (cf. Lund and Norris, 1955; Norris and Lund, 1955).

In relation to the facts reported in this paper, Norris and Fohn (1959) reported the important observation that the rate of oxygen consumption in the root tip (0–5 mm) is photoreversibly inhibited by carbon monoxide. This fact together with others presented in this and previous papers (Lund, 1931; Lund and Kenyon, 1927; Rosene and Lund, 1935) would now appear to be a conclusive demonstration that the bioelectric field in these polar tissues is generated by the oxidation-reduction process in the oriented cytochrome system in the polar cells.

The electric field (Lund, Gunter and Wilkes, 1947; Rosene and Lund, 1953) of the root tip results from an integrated production of the electrical energy by the individual polar cells exhibiting a field intensity which corresponds to (a) the germinal behaviour and structural polarity of the tissue, and (b) to the corresponding polar distribution of concentration of the cytochrome oxidase system.

The fact of algebraic summation of observed cell potentials now provides the basis for a continuously maintained electrical correlation between cells based on oxidative

processes in such a system, enabling the cells to act continuously as an orderly system in early growth and morphogenesis (Lund, *et al.*, 1947).

These facts considered individually and collectively now also provide a rational and factual basis for the observed experimental fact that properly applied potential difference can reversibly determine the orientation and rate of growth in such systems as the egg of *Fucus* (Lund, 1923), regenerating stem segments and disassociated cells of *Obelia* (Lund, 1921, 1947), the root and oat coleoptile (Lund and Collaborators, 1947, pp. 197, 217), and regenerating segments of *Dugesia* (Marsh and Beams, 1952).

The facts also indicate specifically that the reversible inhibition of rate of growth of the root-apex by the application of an external source of E.M.F. (Lund, *et al.*, 1947) can be brought about by action of an applied E.M.F. on the oriented cytochrome electrode system of these polar tissues. The oriented oxidative process in the cell is linked to the oriented morphogenetic process in polar systems which makes it possible to control the rate and orientation of the growth process.

In a later paper it will be shown that an applied potential difference to the root can reversibly inhibit the rate of oxidation in the oriented cytochrome system.

PART II: The E.M.F. of the Frog Skin.

Introduction

In the following experiments on the frog skin, which has served for a long time as classical material for studies on bioelectric and transport phenomena, it will be shown that (a) the polar epithelium of the skin exhibits the same effects of carbon monoxide on the electric potential as that shown on the root tip of *Allium cepa* in the preceding section, and (b) that the same type of oriented gradient of concentration of cytochrome oxidase occurs in this polar epithelial structure as in the root tip. Both are germinal tissues, and both exhibit the highest electric potential where the highest concentration of the enzyme occurs.

Francis (1934) reported that a mixture of 80% carbon monoxide and 20% oxygen in the atmosphere surrounding the frog skin or in Ringer's solution has no effect in the light on the potential of the skin of *Rana temporaria* but has a subsequent depressing effect in the dark. When the skin was again illuminated after exposure to carbon monoxide in the dark for 40 minutes, he observed, anomalously, only a small increase of the potential. He did not observe the behavior of the skin potential after exposure to carbon monoxide or light, nor does he mention the type of illumination. Taylor (1935) reported that the skin potential of *Rana pipiens* is depressed by mixtures of carbon monoxide and oxygen in ratios greater than 4 to 1, but stated that the various degrees of illumination showed that in no case was the potential decreased more by carbon monoxide in the dark than in the light. The conflict between and discrepancy of the findings of these two sets of data indicate a need for a reevaluation of the effects of carbon monoxide and light on the potential of the frog skin.

Methods

The dorsal skins from mature well-fed frogs of *Rana pipiens* were carefully removed, washed in aerated Ringer's solution, drained, and placed in the experimental apparatus

described below, for a one-hour adjustment period before potential measurements were begun. A skin from a single animal was used for each experiment.

The apparatus (Fig. 10) consisted of two tubular and symmetrical lucite chambers A having diameters of 4.5 cm and lengths of 5.5 cm. The skin was stretched onto one of the chambers by means of pins stuck into pieces of cork (not shown) which were glued on the chamber. The skin was oriented to provide readings on different points along the mid-dorsal line of the skin. A wooden vice (not shown) clamped the two chambers together and held tightly the frog skin B between the chambers. Lucite sleeves C permitted the entrance of the arms of the contact cups D (only one shown) which were filled with aerated Ringer's solution and in which were immersed the Zn-Zn sulphate amalgam electrodes E. These electrodes maintained their isoelectric condition within 0.1 millivolt. Electrical contacts were made on the skin with aerated Ringer's solution in glass tubes drawn to capillary tips one millimeter in diameter. The capillary contacts were attached to glass tubing by small flexible pieces of rubber tubing to reduce mechanical stimulation. Each chamber was fitted with gas inlet G and outlet G′ tubes. Rubber finger cots H insured an air-tight seal of the apparatus. Contact cups were attached to 3-way micro-manipulators and the clamp holding the two chambers was attached to a vertical adjustable rack and pinion.

After the contacts had been placed in juxtaposition on opposite sides of the skin by use of the micromanipulators, potential measurements at different points about 5 mm apart on the skin could be made and duplicated within a fraction of a millimeter by manipulation of the vertical rack and pinion and attached millimeter scale. By this procedure, the contacts were always stationary and in precise juxtaposition opposite to each other. By adjusting the height of the solution in D the contact on the skin could

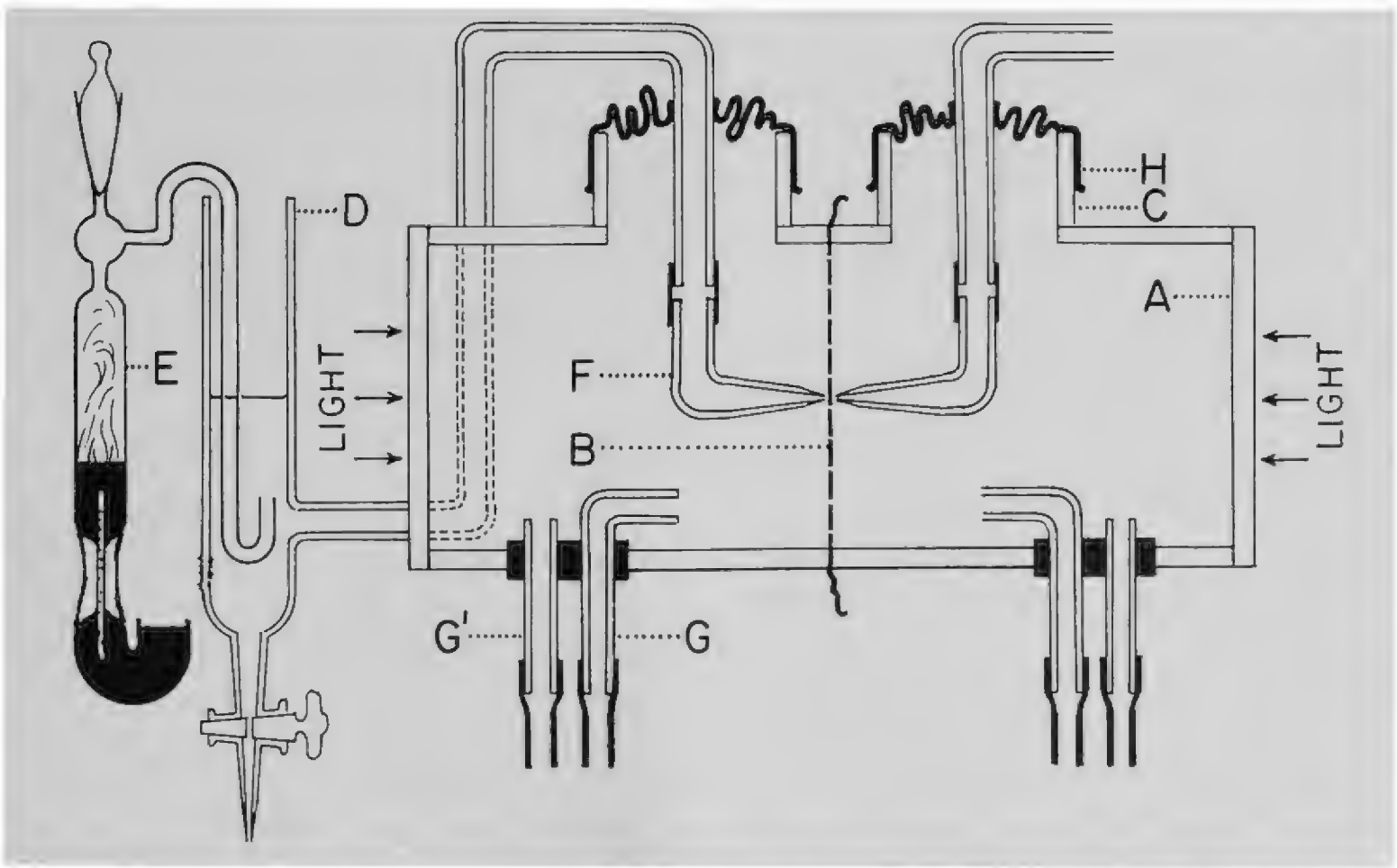

FIG. 10. Experimental chamber. Since the apparatus is double and symmetrical, only one side is labeled. Description in text.

be made precise and less than one millimeter in diameter. The potential measurements at different points on the skin were made, therefore, by moving the skin rather than the contacts. In each one of the experiments, potential measurements were made on the same set of four but different points on each skin. The distances between the four fixed points of a set on different skins varied between 5 mm and 6 mm. Electrical measurements of the frog skin immersed in a solution where potential measurements are made with contacts at a distance from the skin do not reflect important electrical events that occur across the skin at specific points on the skin (Lund, *et al.*, 1947).

Measurements of the four points on the skin were made in sequence every two minutes. Experiments were divided into three 16-minute periods: (1) an initial period in which potential measurements of the skin were made while the skin was exposed to humidified air, (2) a test period in which the effect of humidified carbon monoxide or nitrogen or light was observed on the potential, and (3) a recovery period in which the skin potential measurements were made while the skin was again exposed to humidified air.

The electrical potential measuring circuit was a high impedance vacuum tube voltmeter specially built in our laboratory.

Both sides of the skin could be uniformly illuminated through the ends of the chamber by 100 W incandescent projection bulbs. The heat rays from the bulbs were absorbed by water contained in flasks (not shown) which were located between the bulbs and the chamber windows (Fig. 1A). The intensity of the light on each side of the skin was 300 foot-candles, measured by a light meter. The temperature in the chambers as well as outside during any one experiment varied less than ± 0.5 C.

Results

The Absence of Effect of Light and Constant Temperature on the Potentials. Curves A, B, C, and D of Fig. 11 represent typical potential differences across the skin at four different points on the skin exposed to humidified air in the dark and in the light. The four points were 5 mm apart. Curve A represents potential measurements taken on a point located at the most anterior portion of the skin. Curves B, C, and D represent potential measurements taken from points which were located progressively more posteriorly.

The procedural sequence in the determinations of the potentials at four different points of the skin, designated by curves A, B, C, and D above, was followed in all the experiments to be presented below.

When both sides of the skin were illuminated for a period of sixteen minutes it was observed that light did not alter the potential across the skin at the four points compared to the potentials in the dark. Curves T and T′ represent the temperatures of the left and right chambers, respectively, in the dark and in the light. No significant change of the temperature in the two chambers was observed during the period of illumination. It may be concluded, therefore, that the potentials of a frog skin exposed to humidified air and this temperature variation in the chambers are unaffected by illumination for a sixteen-minute period, a time period of illumination used for all experiments to be presented below.

Effect of 80 per cent Carbon Monoxide and 20 per cent Oxygen in the Dark or Light. When a frog skin is exposed to successive periods of humidified air in the dark, humidi-

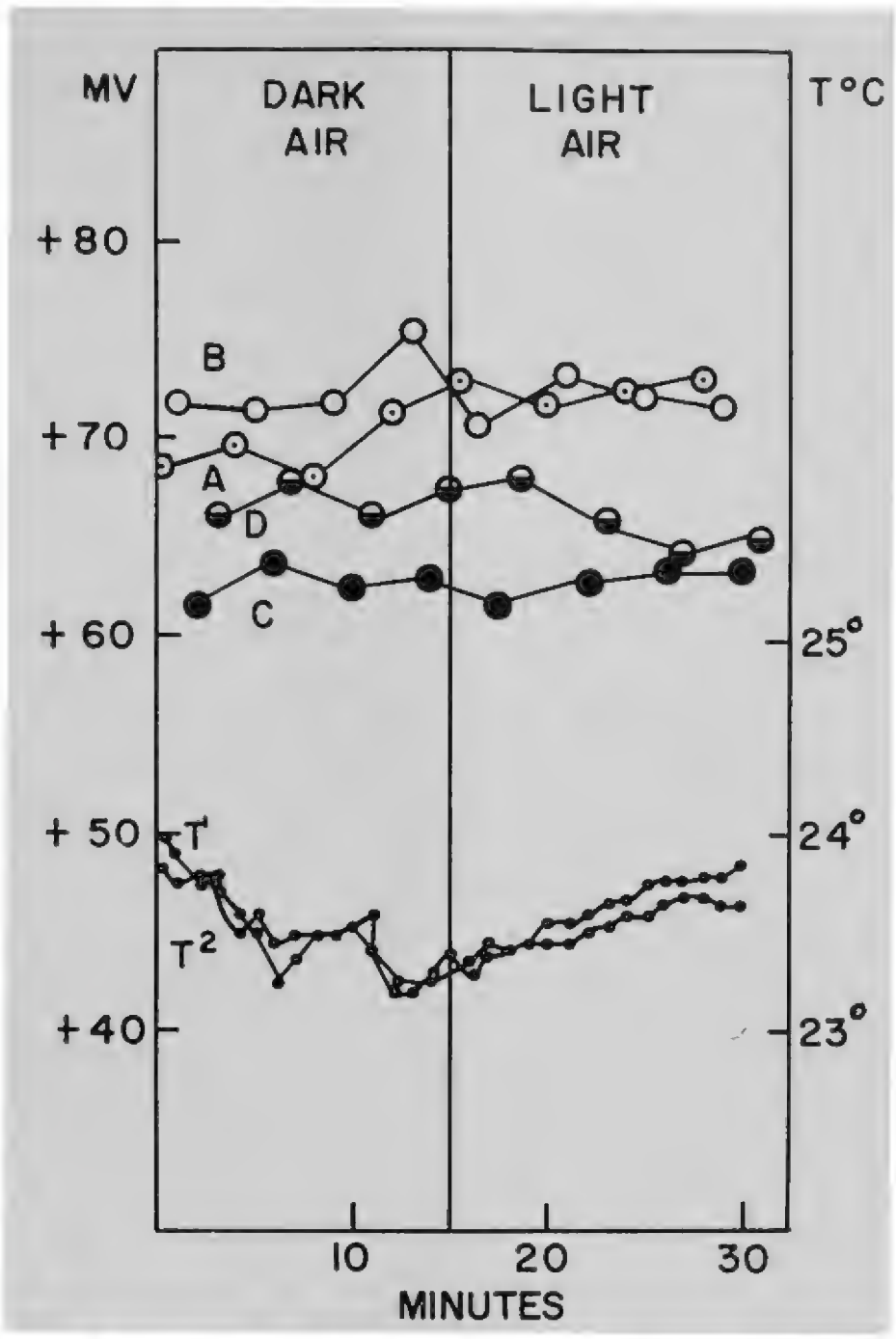

FIG. 11. Effect of light on the potential of an isolated frog skin and on the temperature in the experimental chambers. Curves A, B, C, and D have millivolts as their ordinates and represent potential measurements made at four different points of the skin. In this and all following figures the positive electrode contact was located on the inside of the skin in juxtaposition, opposite to the negative electrode contact located on the outside of the skin. Curves T and T′ have temperature in the experimental chambers as ordinates. The chambers were filled with moist air.

fied mixture of 80 per cent carbon monoxide and 20 per cent oxygen in the dark, humidified carbon monoxide mixture in the light, and humidified air in the dark, no change in the potential measured at four points of the skin, as shown in the typical curves of Fig. 12, are discernible, other than a general drift of all the potentials to lower values, as would be expected in the isolated skin. It may be concluded, therefore, that 80 per cent carbon monoxide and 20 per cent oxygen under the experimental conditions has no obvious effect upon the potentials of the frog skin. This conclusion is contrary to the findings of Taylor (1935) using *Rana pipiens* and Francis (1934) using *Rana temporaria.*

Effect of 90 per cent Carbon Monoxide and 10 per cent Oxygen in the Dark or Light. Experiments were run with mixtures of 90 per cent carbon monoxide and 10 per cent oxygen. The results practically duplicated those of experiments represented by Fig. 12, and hence, curves are not shown. In both sets of experiments the particular mixtures of carbon monoxide and oxygen, under the experimental conditions, had no effect upon the potentials of the frog skins.

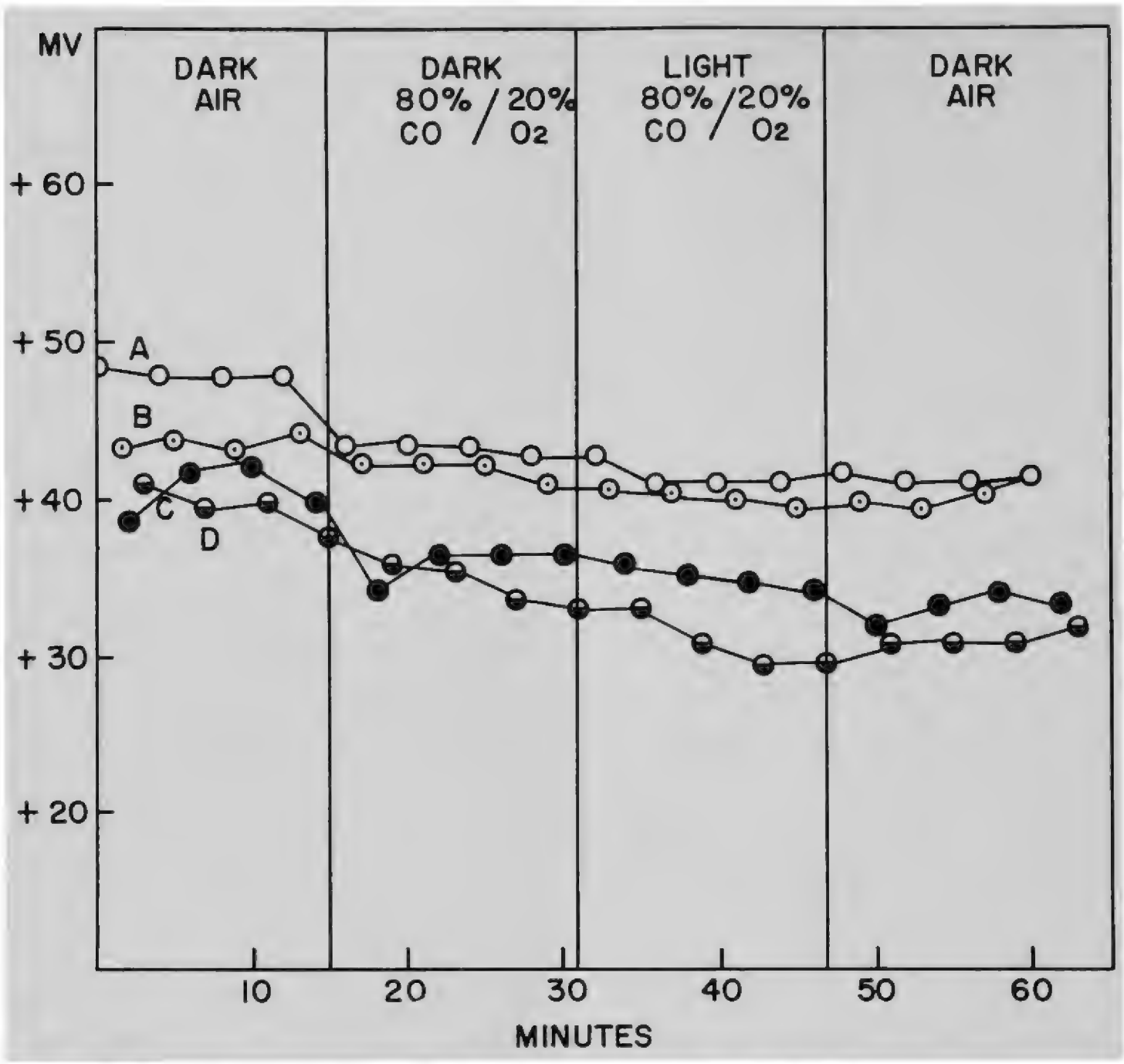

FIG. 12. Typical time course curves showing the absence of effect of 80% carbon monoxide and 20% oxygen on the potentials of an isolated frog skin in the dark and the light. Curves A, B, C, and D represent potential measurements made at four different points of the skin.

Effect of 100 per cent Carbon Monoxide in the Dark or Light. Figs. 13 and 14 show typical results obtained from experiments when skins are exposed to 100 per cent carbon monoxide. The curves in Fig. 13 show degrees of inhibition of the frog skin potentials upon exposure to 100 per cent carbon monoxide in the dark similar to those obtained when a skin is exposed to 95 per cent carbon monoxide in the dark. The curves in Fig. 14, however, show much higher degrees of inhibition. In all instances (Figs. 13 and 14), light reverses the inhibition produced by 100 per cent carbon monoxide. In one curve (curve B, Fig. 13), a rebound potential may be noted while the others show almost complete recovery. Complete reversal of the 100 per cent carbon monoxide inhibition is not attainable in most cases, apparently due to a too prolonged oxygen deficiency of the skin in the experiment.

The rebound, or reversible increase above normal of the E.M.F. is a commonly observed effect after exposure of the skin for short periods to the absence of oxygen (Fig. 15). The oxidation-reduction theory provides a clear explanation and basis for this phenomenon (Lund, 1928a).

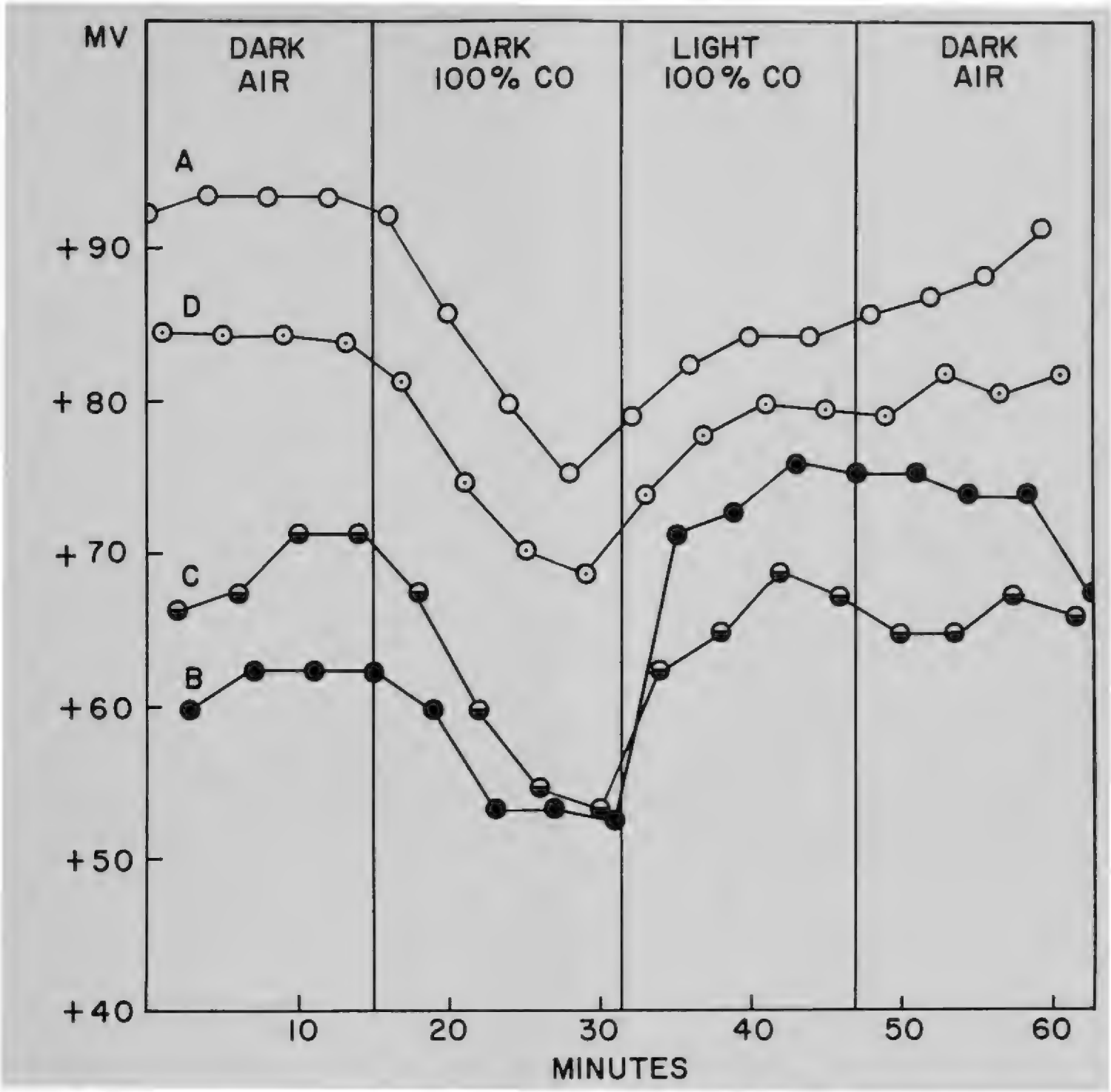

FIG. 13. Typical time course curves showing the effect of 100% carbon monoxide on the potentials of an isolated frog skin in dark and in light. Curves A, B, C, and D represent potential measurements made at four different points of the skin. Differences in the sets of curves of figures 13 and 14 are due to difference between different frogs.

Effect of 100 per cent Nitrogen in the Dark and in the Light. As a final control experiment it was necessary to show to what degree inhibition of the potential by 100 per cent carbon monoxide was due specifically to carbon monoxide or to lack of oxygen. It is seen from the curves of Fig. 15 that (a) 100 per cent nitrogen—absence of oxygen—in the dark slowly depresses the potential, and (b) light has no effect upon the depression of the potential by 100 per cent nitrogen (absence of oxygen). These results show that a part of the carbon monoxide inhibition in Fig. 14 may be attributed to prolonged oxygen lack. But, light reverses the carbon monoxide inhibition and the degree of potential depression due to carbon monoxide in the dark is much greater than that due to nitrogen. These facts show that the inhibition of the potential by carbon monoxide and its reversal by light is uniquely due to the carbon monoxide–cytochrome oxidase complex.

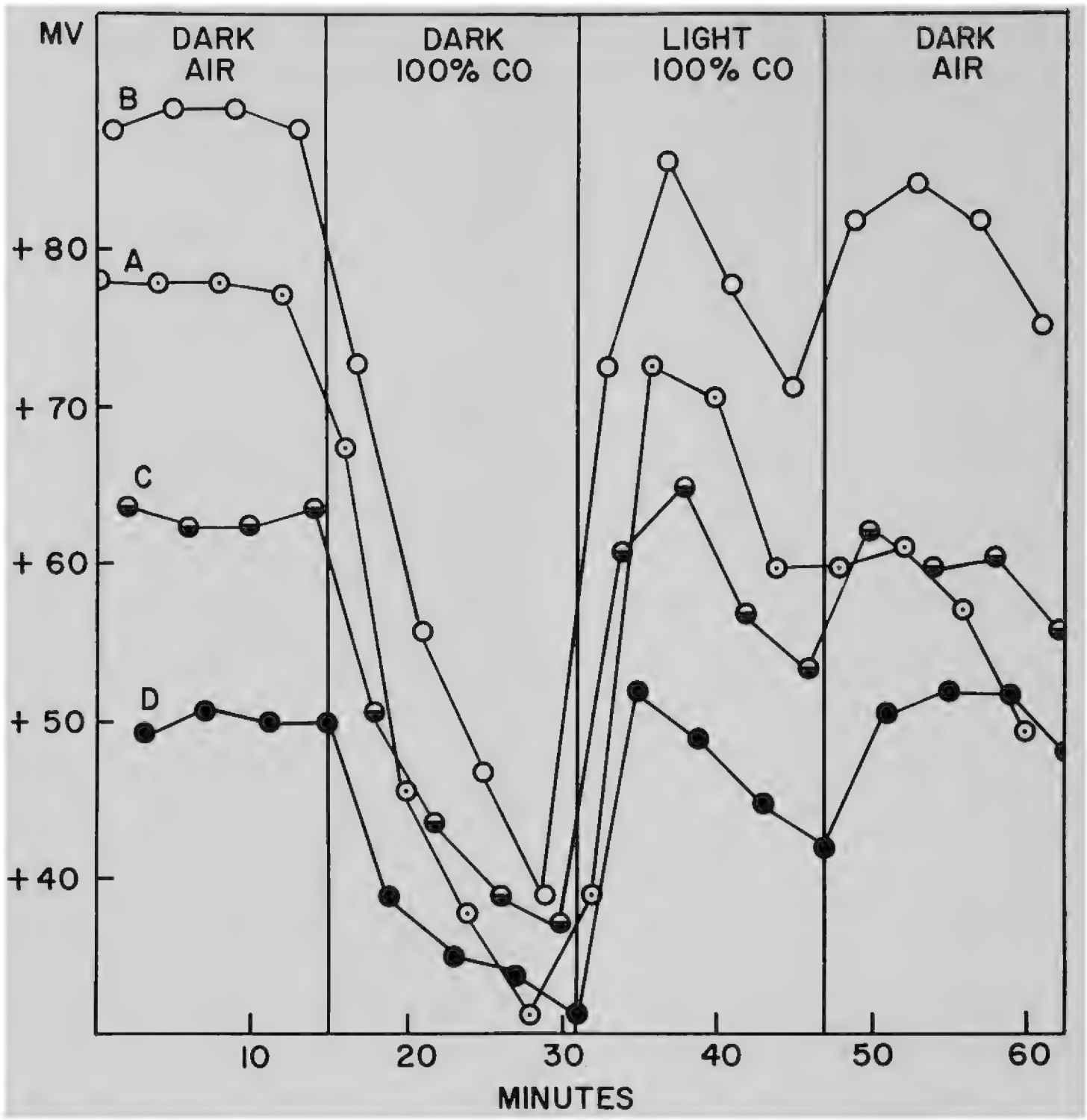

FIG. 14. Typical time course curves showing the effect of 100% carbon monoxide on the potentials of an isolated frog skin in dark and in light. Curves A, B, C, and D represent potential measurements made at four different points of the skin, each point having a characteristic magnitude of E.M.F. and are different from one another.

Unequal Distribution of Potentials on the Skin. It is clear from all the curves that each spot on the skin exhibits its own particular magnitude of E.M.F. which characterizes the curve as a whole. This fact is clearly shown when the skin is suspended in a gaseous medium, while when the skin is immersed in a conducting solution like Ringer this non-uniform distribution is not readily detected because of local short circuits in and on the skin.

When an attempt is made to so-called "short circuit" the skin by applying an external source of E.M.F. in series with the skin (as has so frequently been done) there is no possibility of short circuiting the skin at *all* points simultaneously. It is seen in the curve that different points of a skin may vary from 50 to 85 mv. In other experiments differences of 400 per cent have been observed. These facts alone leave the common use of

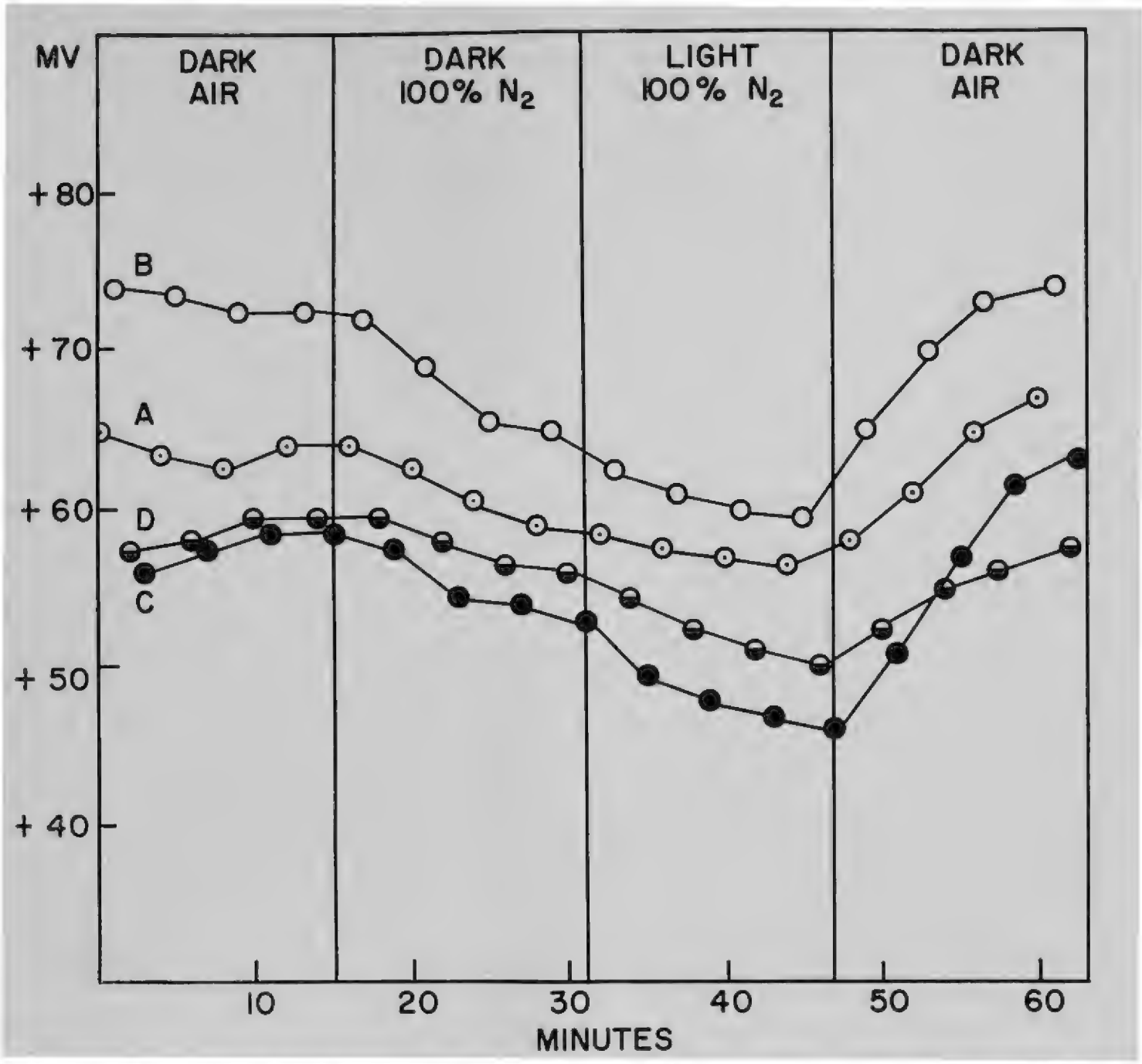

FIG. 15. Typical time course curves showing the effect of 100% nitrogen on the potentials of an isolated frog skin in dark and in light. Curves A, B, C, and D represent potential measurements made at four different points of the skin.

"short circuit" procedure open to serious question. This problem will be fully considered in another paper.

Localization of the Cytochrome System by the Nadi Reagent.

In 1885 Ehrlich showed that an injection of a mixture of alpha-napthol and dimethyl-p-phenylenediamine is catalyzed by living tissues to form indophenol blue. The enzyme accomplishing this was then called indophenol oxidase. Keilin (1929) observed that cells of yeast, muscle and other tissues contain an insoluble, thermolabile oxidative enzyme which catalyzes this same mixture (called the Nadi reagent). Production of this blue color was inhibited by carbon monoxide in the dark.

Keilin and Hartree (1953) found that preparations of indophenol oxidase catalyzes the oxidation of reduced cytochrome c and the Nadi reagent. These and other facts led him to advance the theory that indophenol oxidase and cytochrome oxidase are the same enzyme. This theory has been widely accepted today, and the Nadi reaction has been frequently employed for the histochemical detection and localization of cyto-

chrome oxidase. Dimethyl-p-phenylenediamine acts as a hydrogen donor. *In vitro*, the reaction occurs when the reducing systems (dehydrogenases) are replaced by dimethyl-p-phenylene-diamine.

Without proper precautions, however, the development of the blue color from the Nadi reagent by biological material cannot be taken as evidence, *per se*, for the presence of cytochrome oxidase. Lison (1936), in his review, has pointed out that there are two Nadi reactions given by tissues: (1) the G Nadi given by fresh tissues in which the color developed is diffuse and prevented by moderate heat (55 C), formalin, alcohol, acid, alkali and by freshly boiled aqueous solvent; (2) the M Nadi given almost exclusively by myeloid leucocytes is heat stable, insensitive to formalin, alcohol, and alkali. It is obvious that the M Nadi reaction is not given by cytochrome oxidase. Presumably, the M Nadi reaction is due to fat peroxides.

Van Fleet (1952) pointed to the pitfalls of enzyme localization techniques observed directly in plant tissues—for example, localized absorption of the indicators, the possibility that the site of the indicator reaction is not the site of the reacton itself, and the non-specificity of many of the indicators. On the other hand, there is much to be said for these direct methods designed to reveal qualitatively the distribution of the enzyme. It is well known that the activity of many enzymes is dependent upon cellular activity and that histolysis and extraction methods may cause a loss of their activity. Many of the results of experiments using the Nadi reagent are difficult to interpret because of failure to control carefully the reaction with proper pH and solvents, to test the absorption of previously oxidized Nadi, and to use specific inhibitors of cytochrome oxidase.

A widely quoted example of the proper use of the Nadi reagent to detect the presence and localization of cytochrome oxidase is given by the work of Moog (1943). She exposed fresh chick embryos to Nadi reagent and observed gradients in the distribution of the blue color. Azide, which is an inhibitor of cytochrome oxidase, prevented the color reaction. As a check on the possibility that the indophenol blue might be reduced to the leuco form as fast as formed, phenylurethan was used to saturate the reducing systems. In this case, a slight decrease in "standard coloration" time was observed. Straus (1954) used the Nadi reaction and azide controls for microquantitative colorimetric determination of cytochrome oxidase in mitochondrial suspensions of rat kidney.

Thus, it is seen that the applicability of the Nadi test for the distribution and localization of cytochrome oxidase in living tissue seems well substantiated. The purpose, then, of the following experiments was to test the Nadi reagent on the skin in order to correlate qualitatively the distribution of cytochrome oxidase and the distribution of the electrical potential in the layers of the skin. Hand sections of the dorsal and ventral skins of frogs when exposed to the reagent and examined under a dissecting microscope, developed in ten minutes a distinctive blue color in the epidermal layer of the skin. The corium layer did not show any visible blue coloration. Frozen sections of frog skin cut at 20 microns and exposed to the reagent verified this observation. The fineness of the structure of this layer, however, prevents any definite statement at present as to the intracellular distribution of cytochrome oxidase. However, sections show a very distinct gradient of highest intensity in the basal layer. Azide and formalin prevented the catalytic formation of Indophenol blue by the frog skin when exposed to the reagent, indicating the specificity of the Nadi reagent for the detection of cytochrome oxidase and its localization in the same layer of the skin that gives rise to the E.M.F. These findings

were originally indicated by Alcock (1906), and later confirmed by Ottoson (1953), Engbeek and Hashiko (1957), and Sheer and Mumbach (1960).

Discussion and Theory

A very large amount of the literature dealing with the E.M.F. of the frog skin is devoted to the effect of concentrations of different ions on the E.M.F. and to the relation between the "active transport" of ions (particularly sodium) and this E.M.F. There has been no critical evidence, however, which shows whether the ion transport processes determine the skin E.M.F. or whether the skin E.M.F. determines the ion transport process. Ussing (1949), Linderholm (1952) and Koefoed-Johnsen and Ussing (1960), for example, are of the former opinion although they acknowledge that "active transport" of sodium is dependent upon oxidative metabolism, hence the "sodium pump" concept. For comprehensive reviews, see Huf (1955) and the proceedings of a symposium on membrane transport and metabolism held in Prague, 1960 (Kleinzeller and Kotyk, 1960).

Our experiments show that the inherent ("resting" potential) and continuous production of electrical energy by the polar germinal cell layer of the frog skin is linked with trans-tissue ionic gradients. It is highly probable that this energy is generated by the cytochrome system when oxygen is available for its function as an oxidative respiratory enzyme in the absence of unequal concentration of ions in the medium.

It should be obvious that the potential of this oxidation process may be algebraically summed with other types of potentials due, *e.g.*, to differences in concentration, diffusion, etc., which need not and often could not contribute as a maintained source of useful energy for transport. Typical examples of the inadequacy of the application of concentration potential theory to explain all the phenomena are given in Walker's table four, p. 487 (1955), and by Oda (1961) on cell membrane potentials in *Chara* and *Nitella*.

So far as is known, structurally polar cells (tissues, organs and organisms of both plants (Lund, 1929) and animals) exhibiting polar growth always develop correspondingly oriented E.M.F.'s and flow of electrical currents. Since the oxygen tension controls the rate at which oxygen reacts with cytochrome oxidase in the terminal step of the respiratory chain, and correspondingly determines the magnitude of the E.M.F. and continuous output of electrical current (Lund, 1928a, b, 1931), this system must act as an oriented cytochrome oxidation-reduction electrode system.

The cytochrome-electrode system may be oriented and linked with the polar fine structure of the membrane, thus giving rise to all or part of the membrane potential difference. It is possible that it serves as a source of energy for the oriented transport "machine" or "pump."

Finally, attention must be called to an important paper by F. O. Schmitt (1930) in which he clearly demonstrated the specific effects of carbon monoxide and its reversal by light on the frog nerve. His results correspond to those reported herein but seem to have been overlooked by recent investigators.

General Summary

1. The E.M.F. and electrical energy generated in the onion root tip and in the frog

skin under conditions of the experiments reported in this paper appear to be derived from the oxidation-reduction mechanism of the respiratory process, consisting of an oriented electron transfer unique in magnitude at each spot along the root and on the skin.

2. That the E.M.F. and electric current are generated by and in the electrically and structurally polar germinal layer of the frog skin is fully confirmed.

3. The cytochrome system appears to be the immediate source of the electrical energy which may be available for the ion "pump" and other requirements for active transport.

4. The data from the root tip and frog skin epithelium experiments show that the cytochrome system must be an oriented system in order to provide orientation to the flow of electrical energy. This vector property of the system is apparently associated with or determined by macromolecular structure and expresses itself in the corresponding visible polar axial structure, form of the columnar epithelial cell, and meristem of the root with its summation of individual cell E.M.F.s.

5. Bioelectric potential differences in cells and tissues under particular conditions are often the algebraic sum of different kinds of potentials such as those caused by diffusion, differences in concentration, Donnan equilibria, electrokinetic charge and the polar oxidation-reduction process. This is shown by the fact that Nernst concentration potential theory has never been adequate to explain all the facts of many past experiments. The observed oxidation-reduction potential mechanism may provide a major maintained source of electrical energy for useful work in the cell.

6. The magnitude of E.M.F. across the frog skin is found to be characteristically different in various small areas of the skin. This produces a complex pattern of bioelectric field in the medium adjacent to the skin surface.

7. The pattern of the electric field ("resting" field potentials) may undergo spontaneous variations, due to variation in the electrochemical flux equilibrium state of the oxidation-reduction system (cytochrome) of the polar cells in the frog skin and root tips.

8. The kinetics of the flux equilibrium state of the cytochrome electrode system and pattern of the electric field in the root and the frog skin can exhibit states of excitation (action potentials) due to external stimuli, or from nervous origin, similar to electric organs.

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